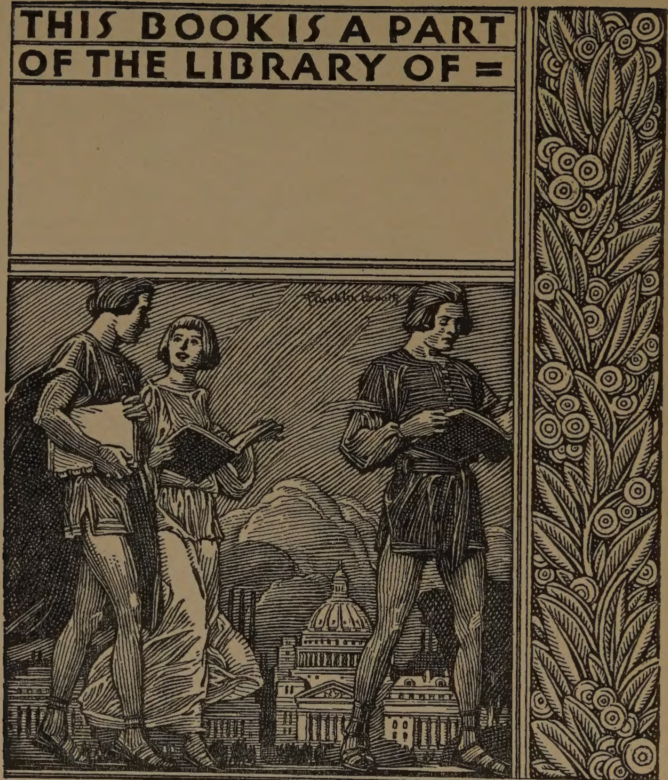
Third Edition

HOUSEHOLD PHYSICS

By WALTER G. WHITMAN



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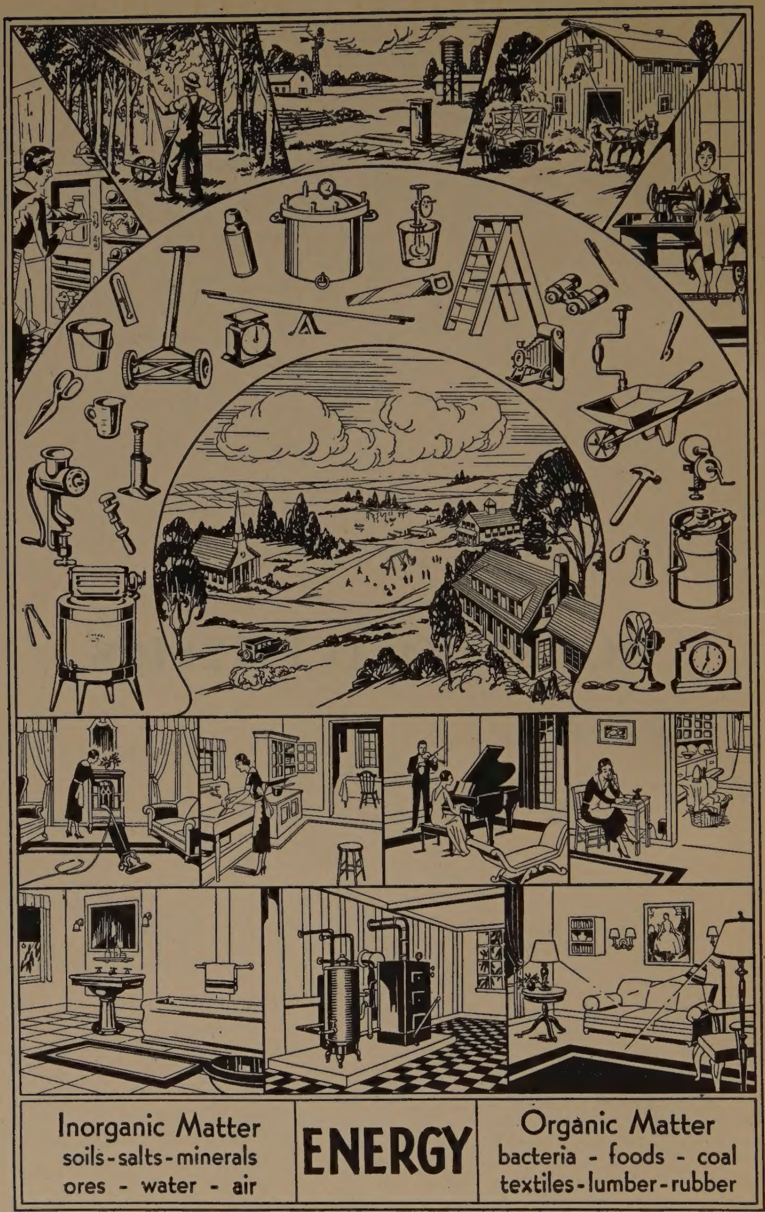
HOUSEHOLD PHYSICS



Frontispiece

All our household devices are made of matter, but no use of them is possible without the addition of energy.

HOUSEHOLD PHYSICS

BY

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FOREWORD

In this third edition the general plan of the first book has been retained, but many changes and additions have been made. Several chapters have been changed very little; others have been completely rewritten; and some topics have been expanded into whole chapters. Important changes will be found in the chapters on electrical devices, illumination, and radio. Six new chapters added are: protection against fire; air conditioning; electricity in everyday life; visual aids; the camera and photography; and solutions and other dispersions.

Two chapters which are quite largely academic have been placed nearer the end of the book, and the chapters entitled " Machines of the Home " and " The Automobile " have been introduced quite near the beginning. Throughout the book, the everyday experiences of the students have been used as a base from which to develop the concept of the fundamental laws. In most chapters the student is led from practical everyday situations to the fundamentals of pure physics.

So rapid is progress in practical science that the average home of today has much equipment that was either unknown or was in the early stages of development ten years ago. Every year man in a progressive community becomes more and more dependent upon devices of his own creation which make use of the principles of physics. The management of the modern home involves problems of health, work, comfort, and recreation. The automobile and radio are considered essential by the average person. We are daily increasing the devices which have automatic control. This is notably true in our heating and cooling systems. There is no question but that greater knowledge of the underlying principles and an understanding of the operation of many of these household devices will increase their efficiency and cut down the repair bills. It is also a matter of satisfaction to many to understand "how it works." The book presents practical physics adapted for girls both in general and in home economics courses. For this reason applications of physics in the home are stressed more than applications to industry.

The author wishes to acknowledge the courtesy of the following manufacturers, publishers, and institutions that have been of material assistance in the matter of illustrating the book:

The Edison Lamp Works, General Electric Company, Standard Oil Company, Landers, Frary and Clark, Singer Sewing Machine Company, Crane Company, Westinghouse Electric and Manufacturing Company, Bausch and Lomb, *Popular Mechanics,* Johns Manville Company, U. S. Weather Bureau, Metropolitan Ice Company, L. J. Wing Mfg. Company, Gem City Stove Mfg. Company, Heatilator Company, Kewanee Boiler Company, American Radiator and Standard Sanitation Company, American Builder and Building Age, Electrol Inc., General Gas Light Company, Carrier-Lyle Company, Silica-Gel Corporation, Summit Manufacturing Company, Libbey, Owens-Ford Glass Company, W. H. Wright of Lick Observatory, Nela Park, Engineering Department of General Electric Company, Research of Eastman Kodak Company, Bell Laboratories of the American Telegraph & Telephone Company, American-La France-Foamite Corporation, *Popular Science Monthly,* Frigidaire Division of General Motors Company, Radio Corporation of America, Illuminating Engineering Society, Gamewell Company, American Gas Association, The Polaroid Corporation, The American Sugar Refining Company, and Agfa Ansco Corporation.

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HOUSEHOLD PHYSICS

CHAPTER I

INTRODUCTION: MATTER AND ENERGY

What makes things as they are? Since man's earliest existence, he has come in contact with things he could see and feel. Long ages ago he discovered that a moving stone or arrow was more useful to him in procuring game for food than the stone or arrow at rest. He understood in a practical way the value of having energy combined with matter. The natural world of today is not so very different from his world, but our artificial environment is almost beyond description. Every labor-saving gadget found in the modern home is useful only because in use both energy and matter are combined. Matter and energy must, then, be about the most important things in the world. True, and more than that, they are, perhaps, the only things needed to make up a world. Let us consider what these two words include. By definition, *matter is anything which fills space and has weight,* and *energy is the ability to do work.* Coal (matter) is of value because it gives heat (energy); and the electric lamp (matter) is used for its light (energy). We receive heat and light from the sun, but the sun is matter, and without it we would have no heat or light.

It is difficult to understand how heat and light can come to the earth from the sun, unless there is some medium connecting the two bodies which can transmit the energy. We can understand how waves travel in water and how sound waves travel in air. Scientists have invented a hypothetical medium without weight which they think of as filling all space. A disturbance set up in the sun may send waves through this medium called the *ether* in all directions. It is perhaps easier to picture the transmission of heat and light through the ether than across a blank space. There are, however, many scientists who doubt the existence of the ether. Its presence has not been proved, so at best we can only think of it as the ether theory. The whole universe is made up of just these two things — matter and energy — with a possibility of a third, the ether. The properties of things in this world depend upon the kinds of matter in them and upon the types of energy they are able to give up.

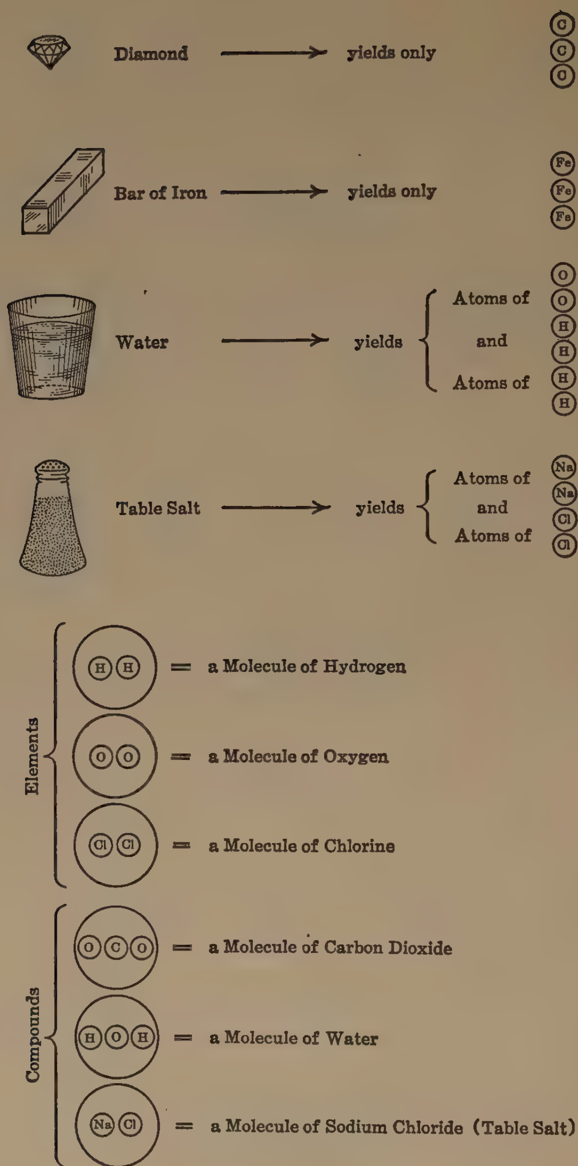


FIG. 1.—Elements have only one kind of atoms. Compounds contain two or more different kinds of atoms. The diamond and iron are elements. Water and table salt are compounds.

Constitution of matter. Matter is not continuous but is made up of tiny particles called *molecules* which are too small to be seen with a microscope. It has been estimated that an ordinary drinking glass holds about 1,865,000,000,000,000,000,000,000 molecules of water. A British scientist gives us this picture to help us sense the size of molecules. If a tiny hole is made through the glass wall of an ordinary small vacuum electric-light bulb which would permit molecules of air to enter it at the rate of 1,000,000 per second, the bulb would not be filled for about 100,000,000 years. These ultramicroscopic particles are in perpetual vibration and move back and forth across the spaces between molecules. Hydrogen molecules at room temperature may have a speed of a mile a minute. Molecules vary in size, weight, and composition.

Molecules are made up of smaller particles — *atoms*. The atom is the smallest particle of matter that can exist as matter. However, the atom is believed to be made up of still smaller particles. Theories of the composition of atoms are not in agreement, but it is generally accepted that there is a nucleus containing an excess of *protons*, and about this are orbits in which *electrons* revolve. Electrons are particles of negative electricity, and protons are particles of positive electricity.

Elements and compounds. An element is matter that cannot be separated into anything but itself. Its molecules are made of atoms which are alike. A compound is matter composed of two or more different kinds of elements. Its molecules contain unlike atoms. Sodium, chlorine, carbon, and oxygen are elements. But sodium chloride and carbon dioxide are compounds. Probably not more than 92 elements exist in the whole world, but, from these, thousands upon thousands of compounds are made.

The chemist has a symbol for each element as:

O — oxygen	C — carbon	Na — sodium
H — hydrogen	Cl — chlorine	Fe — iron

A group of unlike atoms in a molecule is called a formula. H_2O is the formula for water; CO_2, for carbon dioxide; and NaCl, for sodium chloride.

Energy involved in changing composition of matter. If we heat the compound mercuric oxide in a tube, a gas, oxygen, is driven out, and drops of mercury collect on the cooler part of the tube. The molecules of the compound, mercuric oxide, have been separated by the heat energy into molecules of the element oxygen and molecules of the element mercury. When a piece of magnesium ribbon is heated to a high temperature in air, we have at the start molecules of the elements magnesium and oxygen. But after the heat energy starts action between

them, the magnesium atoms and oxygen atoms unite, liberating both heat energy and light energy and at the same time produce new molecules of the compound magnesium oxide. When an electric current (electrical energy) is passed through water containing a little acid to make it a better conductor of electricity, the molecules of water separate into the two elements hydrogen and oxygen. When hydrogen is burned in air, the hydrogen and the oxygen of the air unite, forming molecules of water. This is a chemical process in which the chemical energy produces heat and light. We may mix a teaspoonful each of cooking soda and cream of tartar in the form of dry powders, and nothing happens. But let us dissolve a teaspoonful of cooking soda in a glass $\frac{1}{4}$ full of water and a teaspoonful of cream of tartar in another glass $\frac{1}{4}$ full of water and then pour one solution into the other. Instantly there is vigorous bubbling or effervescence. The molecules of compounds often react much better in solution than they do in the solid state. If baking powder is mixed with flour when making biscuit, the addition of water or milk will set free this escaping gas, carbon dioxide, which will make the dough porous.

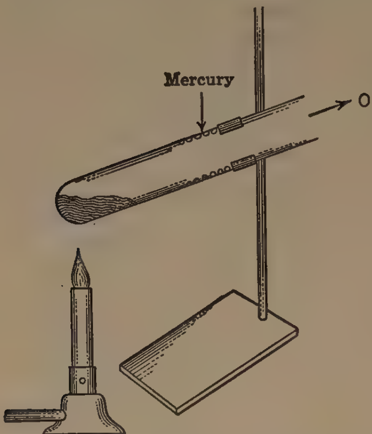


FIG. 2.—What kind of energy is used to separate oxygen from mercury?

How shall we classify things? There are certain intangible things that we speak about even if we cannot understand and explain their ultimate nature. These include the mind, thought, time, and space. We may group them under the heading *abstract ideas* and not include them as physical things. Everything that takes up room and has weight is *matter*. Everything that can do work or that can be transformed into something that can do work is *energy*. If you were asked to classify air, water, earth, and light, you could tell at once that water and earth are matter. Air seems weightless, perhaps, though it fills the room. It is not difficult, however, to weigh the air. It is the weight of the air that gives the atmosphere its pressure. You will then classify air as matter. It may be more difficult to decide about light. It does not

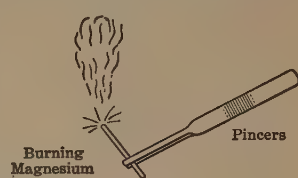


FIG. 3.—What transformations of energy are made when magnesium and oxygen combine?

seem to have weight, but it does fill the room. Suppose that the room is full of air and full of light which has come in through the windows. Could you, by closing all shutters or blinds, keep the light in? Could you keep it full of air? There is a difference here. The air would still be in the room, but the room becomes dark. What has become of the light? Light is radiated through space and disappears as light when it is absorbed by matter. There is a change from light to heat energy when the molecules of matter absorb it, and the molecular vibrations are increased. The heat resulting from the transformation of light can do work; hence light is energy. Matter may be classified in many ways: as solids, liquids, and gases; organic and inorganic; metals and non-metals; and elements, compounds, and mixtures. Energy has no comparable group divisions, for only five kinds of energy exist in the whole universe.

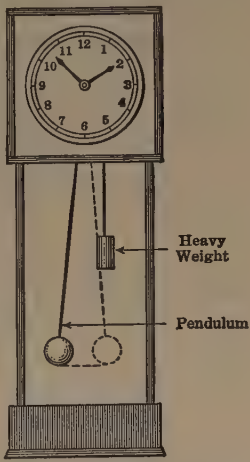


FIG. 4.—What kind of energy makes this grandfather clock go?

Kinds of energy. There is no practical limit to the different kinds of matter, but the kinds of energy are only five. They are: heat, light, electricity, chemical energy, and mechanical energy. Mechanical energy is of two kinds, *potential* and *kinetic*. Potential energy is that mechanical energy which is in a sense stored up. It is so stored when matter is in a state or condition or a position of advantage by virtue of which it can release mechanical energy. Examples of this are: water behind a dam, an elevated weight, or a coiled clock spring. Kinetic energy is the energy of motion. Running water is able to do work, a swinging hammer is able to drive in a nail, a swiftly moving automobile has so much energy that after the engine power is cut off a large amount of frictional resistance from the brakes is required to stop it within a short distance. All these illustrations are examples of how matter in motion can do work upon other matter and in so doing expend kinetic energy.

Transformation of energy. Many physical processes involve the changing of one of these forms of energy into another. In burning coal or gas, chemical energy comes from the union of the fuel with oxygen. The chemical energy produces heat energy. If we use the heat to warm an iron bar until it glows, then some of the heat has been changed to light. We may use mechanical action, as the rubbing of two things together, to produce heat. This principle is applied in lighting a match by friction. Chemical energy from oxidation of food gives us body heat.

Transformation of energy takes place without loss. We cannot transform all the mechanical energy put into a generator into electrical energy because a small part of it is changed to heat in overcoming friction, but the total energy derived from the change equals that before the change. In ordinary changes, energy cannot be created or destroyed. This fact expresses a law of science called the *conservation of energy.* A similar law — *conservation of matter* — is stated thus: Matter cannot be created or destroyed. We may change matter from one form to another and apparently destroy it. When we burn wood there seem to be only a few ashes left; however, if we collect all the products and compare them with the wood and air used in the burning we find that they weigh the same. Although these laws of conservation of matter and energy are apparently true for the type of changes with which we are familiar, many scientists believe that in the sun, when temperatures are enormously greater than on the earth, there may be a transformation of matter into energy. If this is true, the mass of the sun must be ever growing smaller. Also, far off in distant space, energy may, perhaps, be changing back into matter. But these at present are matters of speculation rather than of known facts.

FIG. 5. — What four forms of energy are involved when a candle burns?

When electrical energy passes through the heating element of the electric iron, the heat energy produced means an equivalent loss in electrical energy, the change having been made in the heating element.

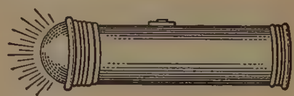


FIG. 6. — What different forms of energy are used and what are produced when a flash-lamp is lighted?

Everyday use of matter and energy. It is through the relations that exist between matter and energy that they are of value to us in our everyday activities. Matter and energy are so dependent upon each other that we can utilize them only in combination.

Of the various forms of energy, heat is perhaps the one which finds the greatest variety of uses in the household. Many years ago, long before the advent of our modern household heat-using devices, Count Rumford recognized the great importance of heat to mankind and expressed it in these words, "All the comforts, convenience, and luxuries of life are procured by the assistance of fire and heat." Mechanical energy is also required wherever matter is moved, and many mechanical household machines are found in and about the modern household. The use of electrical energy is increasing; light energy requires many devices for its effective use; and chemical energy is involved in such household proc-

esses as producing heat, cleaning, and cooking. Thus we utilize all the forms of energy in very practical ways and at the same time use many different kinds of matter.

SUMMARY

1. The foundation things of the universe are matter and energy, and a possible third thing called ether.
2. Matter is anything that occupies space and has weight.
3. Matter is believed to be made up of tiny molecules and molecules to be made up of smaller atoms. Atoms are made up of electrons and protons.
4. An element is matter whose molecules are composed of like atoms. A compound is matter whose molecules contain unlike atoms.
5. There are 92 elements. From these all kinds of matter are made. Matter can be changed, but it cannot be destroyed by any method we know.
6. Energy is involved in all changes in the composition of matter.
7. Energy is the ability to do work. There are five kinds of energy: mechanical, chemical, electrical, heat, and light.
8. Mechanical energy is of two types — kinetic and potential. Kinetic energy is the energy a body possesses by virtue of its motion. Potential energy is the energy a body possesses by virtue of its advantage of position.
9. Energy may be transformed from one kind to another, but it cannot be destroyed.
10. The interrelation of matter and energy is very important since neither is of any use to us without the other.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS AND EXPERIMENTS

1. The ether theory.
2. Possibilities of changing the base metals into gold or platinum.
3. The ultimate composition of matter.
4. Matter is "made out of electricity."
5. Lighting a match by friction involves these transformations in energy: mechanical, heat, chemical, heat, light. Give several other examples that involve at least four changes in energy.
6. How can scientists produce one element from another?
7. Look up the theory that energy may result from the destruction of matter.

CHAPTER II

MACHINES OF THE HOME

Throughout the ages man has gradually improved his methods of applying energy to matter. Today our manufacturing plants have intricate machines which perform both delicate and ponderous pieces of work with an ease and exactness that are not possible for human hands to achieve. When you use the scissors or the paper cutter, the can opener or the bottle opener, when you turn the crank on the pencil sharpener or on the food grinder, you are applying energy to matter through the advantage gained by means of machines. Instead of using your own muscle to operate a machine, you may call upon heat energy, as in the gasoline engine, to run the motor car; or upon water power to run your washing machine; or wind power to pump water; or electrical energy to mix the batter in cooking or to run the sweeper in cleaning.

Force and work. In all mechanical work force must be applied. Force is defined as a *push* or a *pull*. Work is the *overcoming of resistance through space*. You may push against the wall of a building, but you do no *work* upon it unless you move it. On the other hand, you may expend much less force to push a book across the table and you do accomplish work. Work is calculated by multiplying the resistance overcome by the distance through which it is overcome. The unit of work is the *foot-pound*. It is the work done by a force of 1 pound acting through a distance of 1 foot.

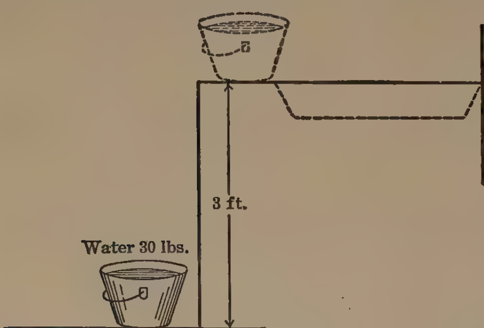


Fig. 7. — When a 30-lb. pail of water is lifted 3 ft., 90 ft-lb. of work are done.

Work (in foot-pounds) = *force* (in pounds) × *distance* (in feet) *through which it acts.*

Suppose that we have on the floor a pail of water which weighs 30 pounds. We lift this a height of 3 feet above the floor to pour it into

the sink. We must use a force of 30 pounds through a space of 3 feet. Hence, the work done equals 30 × 3, or 90 foot-pounds.

Kinds of resistance. Resistance to force may be any one of three kinds, or two or more of them combined. In lifting the pail of water, we are overcoming the resistance of *gravity*. In dragging a trunk over the level floor, we are overcoming the resistance of *friction*. In starting any body which is at rest into motion, or in stopping any moving body, we are overcoming the resistance of *inertia*.

In starting an automobile on a level road the force used must overcome inertia and friction, but in starting the car when headed uphill more force is required because all three resistances, inertia, friction, and gravity, must be overcome.

Simple machines. All the thousands upon thousands of different machines in use are made up of combinations of not more than six different types of simple machines. These six simple machines are further resolved into two groups. The lever, the wheel and axle, and the pulley all belong to the *lever group* because the same fundamental plan of operation applies to all of them. The inclined plane, the wedge, and the screw all belong to the *inclined-plane group* because the wedge is merely a double inclined plane and the screw is a spiral inclined plane.

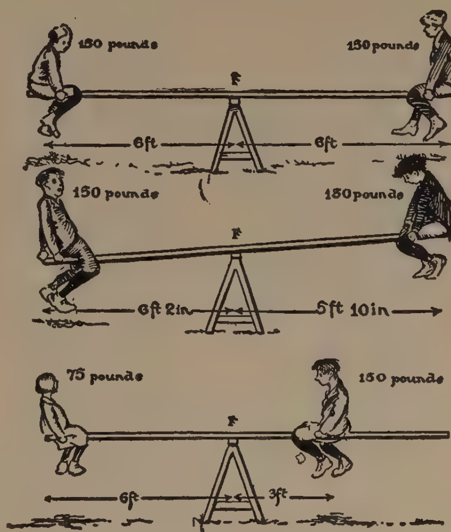


Fig. 8.—Lever principles illustrated by the seesaw.

Lever-type machines. The crowbar, the tack lifter, the nutcracker, the potato ricer, the can opener, and the clock hands are examples of the simplest type of machine, the *lever;* they all belong to the same type of machine as our old friend the "teeter" board or "seesaw." This is so familiar that it may well serve to help us understand the principle involved in the simple lever. With no one aboard, the plank just balances. A 150-pound person 6 feet from the center just balances another 150-pound person 6 feet from the center on the other side. Now let one bend backward so that his center of weight is 6 feet 2 inches from the center, or let the other bend forward

so that his center of weight is 5 feet 10 inches from center. In either case a turning movement about F, the **fulcrum**, takes place: one sinks and the other rises. Replace one of the persons by a 75-pound person; up goes the 75 pounds and down the 150 pounds. But let the 150-pound person come in to the 3-foot mark and there is exact balancing. It is observed that $150 \times 6 = 150 \times 6$, where equal weights are at equal distances, and that $75 \times 6 = 150 \times 3$, where one person weighing half as much as the other balances the other by being twice as far away from the fulcrum. By further experiments we could secure data to verify the law which has already been determined, namely:

In all lever machines balance is secured when force 1 (*resistance*) $\times$ *its distance from the fulcrum equals force* 2 (*effort*) $\times$ *its distance from the fulcrum.*

Or:

$$E \times \text{effort distance} = R \times \text{resistance distance.}$$

Now let us apply this to a few machines for doing real work.

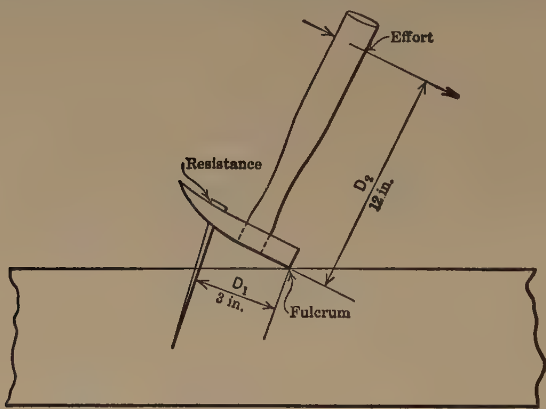


Fig. 9.—The hammer as a bent lever.

A hammer used in drawing a nail is illustrated in Fig. 9. In all lever machines the distance considered must be *the perpendicular distance from the fulcrum to the line of direction in which the force is acting.* The nail offers resistance in a line 3 inches from the fulcrum. The effort applied to pull the nail is acting in a line 12 inches from the fulcrum. If the effort is measured and found to be 20 pounds, then the resistance offered by the nail may easily be determined as follows:

$$20 \times 12 = \text{resistance of nail} \times 3$$
$$240 = \text{resistance of nail} \times 3$$
$$\text{Resistance of nail} = \frac{240}{3} = 80 \text{ pounds.}$$

The pump handle shown in Fig. 10 is a lever, and if the piston rod is pulling in a line 3 inches (perpendicular distance) from the fulcrum, and the effort applied perpendicular to the handle is 2 feet (24 inches) from the fulcrum, the pump handle has a **mechanical advantage** of $\frac{24}{3}$ or 8. That is, the 8-pound resistance at the piston is balanced by a 1-pound force (effort) 24 inches from the fulcrum. The product of effort by its distance equals the product of resistance by its distance; $1 \times 24 = 8 \times 3$.

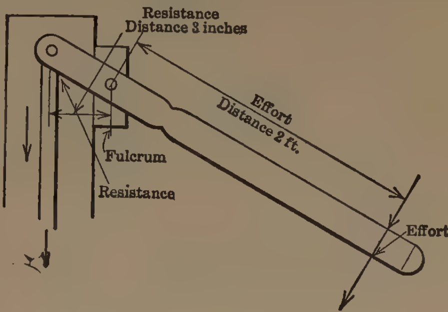


Fig. 10.—The pump handle as a lever.

The wheelbarrow is a lever machine. The axis of the wheel is the fulcrum. If a barrel of flour weighing 196 pounds is centered over a point 2 feet from the fulcrum and a man lifts on the handles 5 feet from the fulcrum, how much effort must he exert to lift the flour, neglecting the weight of the wheelbarrow itself?

$$196 \times 2 = \text{effort} \times 5$$

$$392 = \text{effort} \times 5$$

$$\text{Effort} = \frac{392}{5} = 78.4 \text{ pounds.}$$

Three different relative positions of effort applied, resistance, and fulcrum produce the *three classes of levers* as follows:

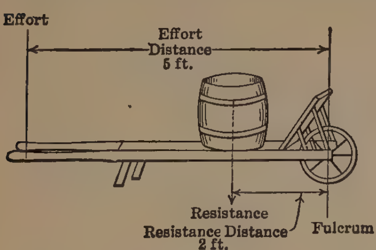


Fig. 11.—How does the wheelbarrow illustrate the lever type of machine?

First. The fulcrum between the effort and the resistance.

Second. The resistance between the fulcrum and the effort.

Third. The effort between the fulcrum and the resistance.

These three arrangements are illustrated respectively by the scissors, the boiler safety valve, and the forearm, in Fig. 12. Study a number of devices, as the piano and typewriter key mechanism, a lemon squeezer, sugar tongs, grass shears, can opener, etc., and determine the position of the fulcrum, effort, and resistance for each.

Advantages of the lever. As was shown in the preceding section, one of the important reasons for the use of the lever is its **mechanical advantage,** whereby one may overcome a resistance much greater than the effort he applies. It is always true, however, that just as much work must be done *on the lever* as is done *by it,* and that, when a smaller

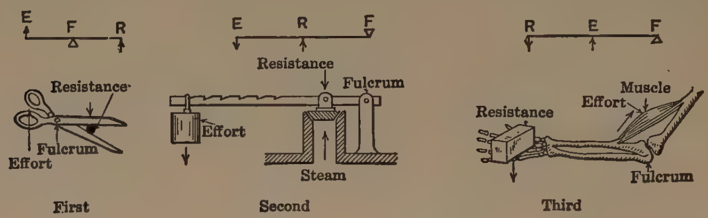


Fig. 12.—Three types or classes of levers, depending upon the position of the fulcrum in relation to the effort and resistance.

effort is applied, it must act through a correspondingly longer distance. This may be expressed in the form of an equation:

Effort $\times$ *distance through which effort is applied* $=$ *resistance* $\times$ *distance through which the resistance is overcome.*

Or:

$E \times$ distance E is applied $= R \times$ distance R is overcome.

Another advantage of the lever is **speed advantage.** The baseball bat illustrates this; one hand acts as the fulcrum, the other as the force. The force is applied on the short arm of the lever and the long arm has greater speed, which is an advantage in driving the ball a long distance. In the human arm, the biceps muscle is attached to the forearm bone a short distance in front of the elbow, which acts as the fulcrum. By contracting this muscle one is able to move the hand rapidly through a long distance, and graceful arm movements are possible. Our arms would be awkward indeed, if we were compelled to do without this type of lever. Are there levers in other parts of the body?

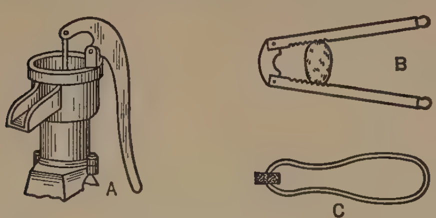


Fig. 13.—Name the class of each of the levers. Reason for your answer?

For speed advantage the work equation of the lever, $E \times$ distance E is applied $= R \times$ distance R is overcome, may be expressed $E \times$ speed

of $E = R \times$ speed of R, since as the motion occurs in the same length of time, the speed is proportional to the distance passed over.

Problem. An old well sweep, Fig. 14, has a heavy weight 3 feet from the fulcrum. This acts as force to lift water in a pail attached to the other end of the pole, which is 12 feet from the fulcrum. If the heavy weight falls 2 feet, how high will the pail be lifted.

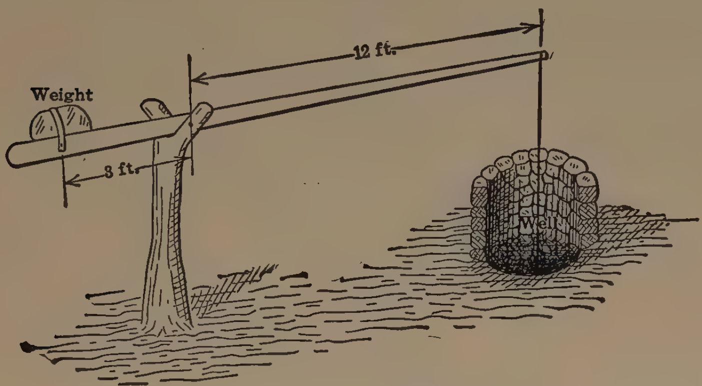


FIG. 14. — The well sweep is a lever.

Solution. The effort and resistance are not given, but from the two arms 3 and 12, we know that the distance they move must be in the ratio 3 : 12. Hence,

$$2 \text{ (distance } E \text{ moves) } : X \text{ (distance } R \text{ moves) } :: 3 : 12$$
$$X = 8$$

The pail would be lifted 8 feet.

If the long arm were 18 feet and the weight 3 feet from the fulcrum, how high will the pail be lifted when the weight falls 1 foot? When it falls 2 feet?

Advantages of a machine. Just like the lever, other machines have both mechanical advantage and speed advantage. But in all machines more work is put into the machine than comes out of it, because, in operating every machine, friction must be overcome in addition to the useful work. What then is the advantage of the machine? The mechanical advantage of the machine lies in the fact that we can accomplish a piece of work by expending a smaller force through a greater distance, or for the speed advantage we may apply a force through a small distance or at slow speed and gain movement through a greater distance or at a higher rate of speed.

Wheel and axle. In the ice-cream freezer, the clothes wringer, egg beater, bread mixer, churn, emery knife sharpener, and windlass, we apply effort in the path of a large circle or at the circumference of a wheel while the resistance is applied at the circumference of an axle. A machine of this type differs in no respect from a lever in principle; in fact, it is a continuous acting lever, as may be seen from Fig. 15. Let *B* be the center of both axle and wheel, *A* the point of application of the effort (*E*) on the wheel, and *C* the point of application of the resistance (*R*) on the axle. Then at any instant *AB* is the effort arm and *BC* is the resistance arm. *AB* is the radius of the wheel, and *BC* is the radius of the axle. We may solve wheel and axle problems by applying the law of levers previously given.

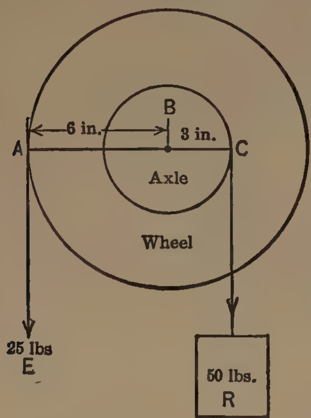


FIG. 15. — Use this diagram to explain how the wheel and the axle constitute in principle a continuously acting lever.

The pulley. Little use is made of the movable pulley in the home, except occasionally for awnings and hammocks; the fixed pulley is used to support the cord running to the window weights. The pulley is another modified lever, as will be seen from Fig. 16. Each sheaf of the pulley is an equal-armed lever. The block and tackle used for moving buildings, pulling stumps, and lifting safes and pianos may have many strands of rope between the movable and fixed blocks. The effort is applied through as many times the distance through which the resistance is overcome as there are strands of rope going from the movable block; hence:

The mechanical advantage of a system of pulleys is equal to the number of ropes which come from the movable block.

The inclined-plane type of machines. Machines of this type, such as the **skid** for loading and unloading trucks, the **wedge** of which the **ax** is an example, and the **screw**, all work on the principle of the inclined plane. The principle in brief is this: The work done in lifting a body is calculated by multiplying the weight by the vertical height to which it is raised. If the weight is not lifted vertically, but is moved along an inclined surface, the force required to move it is less, because the force acts through a distance which is greater than the vertical height to which the weight is lifted. When the force acts in a direction parallel to the incline, then:

$$\textit{Weight} \times \textit{vertical distance} = \textit{force} \times \textit{length of incline.}$$

The principle of the inclined plane is well illustrated by mountain roads. A long road with gentle grade is preferred to a short road with steep grade, because of the greater mechanical advantage of the gentle grade. The screw is a spiral inclined plane. The corkscrew and meat grinder utilize the screw principle.

Complex machines. Many kitchen devices and farm tools are very simple machines, but we also find numerous machines which are so complex that it is difficult to recognize in them any of the simple machines we have mentioned. And yet the sewing machine, the piano player, the automobile, and the reaper are only applications and combinations of various forms of these simple machines. Close examination of individual parts will reveal many surprising facts previously unknown to the user of the machine. Many devices in common use involve other scientific principles besides those of the simple machines; examples of such devices are washers and cleaners. Often gear combinations are a

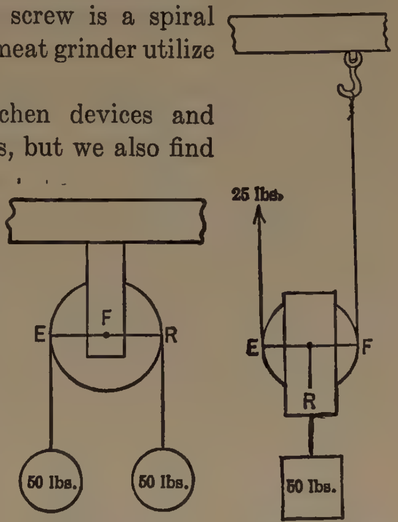


FIG. 16.—The lever principle in the pulley.

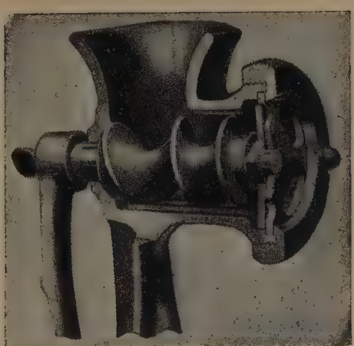


FIG. 17.—The screw principle is used in the food chopper to force the food against the cutting knives.

FIG. 18.—Wheel and axle with gear combination.

means of changing speed. In many household machines, the great advantage is the employment of power other than hand power, such as water power, electricity, etc., in their operation. Among such may be

mentioned dish-washing and clothes-washing machines and vacuum cleaners.

Efficiency of machines. In practice we are unable to get as much useful work out of a machine as we put into it. Friction cannot be eliminated entirely, and a certain amount of energy must be expended in overcoming it.

The ratio of useful work done by a machine to the work done upon it is known as the efficiency of the machine.

If the work accomplished by means of a machine is but three-fourths of the work actually done, its efficiency is 75 per cent. In some machines friction may be reduced by means of roller bearings and lubricants, which thereby increase its efficiency. Ball bearings are found in roller skates and in the bicycle; roller bearings, in heavy machines, as in parts of the automobile.

Vacuum sweepers and cleaners. These devices depend upon atmospheric pressure. A partial vacuum is produced within the machine by pump action or a motor-driven turbine. If the opening to the vacuum chamber is in the vicinity of loose dirt, the inrushing air carries the dirt in with it. The air pumped in or drawn out of the vacuum chamber is returned to the room through a closely woven cloth bag which strains the air and holds all the dirt and dust inside. The hand-operated and the smaller electrically operated machines are "sweepers." They do little more than remove the surface dirt. The "cleaners" are those machines with enough power to really clean rugs and carpets so that removal for beating is unnecessary. The advantages of vacuum cleaning are: less hard work, less dusting, and more healthful air. A permanently installed cleaner is best, but as this means a large outlay for the machine and piping to all the rooms, the smaller portable machines are more common.

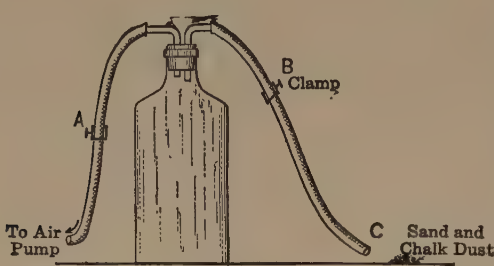


Fig. 19. — Principle of vacuum cleaner.

Demonstration of the vacuum principle. The following demonstration will explain the working principle of the vacuum cleaner. Partly exhaust a large bottle, such as shown in Fig. 19, by means of an air pump. Close *A*. Hold *C* over powdered chalk and coarse sand, and open *B*. The atmospheric pressure causes a rush of air into the bottle, forcing the chalk dust through the pipe with it. Exhaust the bottle as

completely as possible and repeat on another mixture of sand and chalk dust. This time both chalk and sand particles are pushed in. The higher the vacuum in the bottle, the stronger the force of the air on the outside, and the heavier are the particles which may be moved by it.

Vacuum cleaner tests. Three tests may be applied to a vacuum cleaner to determine whether it will meet the requirements.

1. *Vacuum.* Under conditions of use, what vacuum is produced? Is it enough to clean well? Is it so great that it injures rugs and draperies?

2. *Capacity.* What volume of air does the machine draw per minute? The volume of air which passes through is important in determining the size of cleaning tool which may be used and the speed of the air current.

3. *Efficiency.* What percentage of the dirt in a carpet does the cleaner remove?

Vacuum. The degree of vacuum which the machine is capable of developing is easily determined by plugging the entrance tube with a one-hole stopper, and connecting a water or a mercury manometer through the stopper. To measure the pressure under actual working conditions, one may make a hole in the pipe or tube for the manometer connection, then observe the pressure while the machine is in use with the regular attachments.

Fig. 20.—A permanently installed vacuum system.

Volume capacity. It is the partial vacuum and the beating action in some cleaners that loosens the dirt, but it is the moving air that carries it away. In permanently installed plants there are some horizontal pipes, and unless there is a good volume of air to maintain a high speed its load of dirt will be dropped and the pipe clogged. The size of

tool used may to some extent influence the volume of air that will be drawn in, and the power of the machine will determine the volume of air that can be drawn through a given tool.

FIG. 21.—Phantom view of a vacuum cleaner.

The sewing machine. In the sewing machine one can, by a little observation, find levers, wheel and axle, inclined plane, and screw. These simple machines have been ingeniously arranged so that the one combined machine operated by one person will do the work of many

persons who sew by hand. A machine can make three thousand stitches a minute. We owe much to Elias Howe who invented the sewing machine.

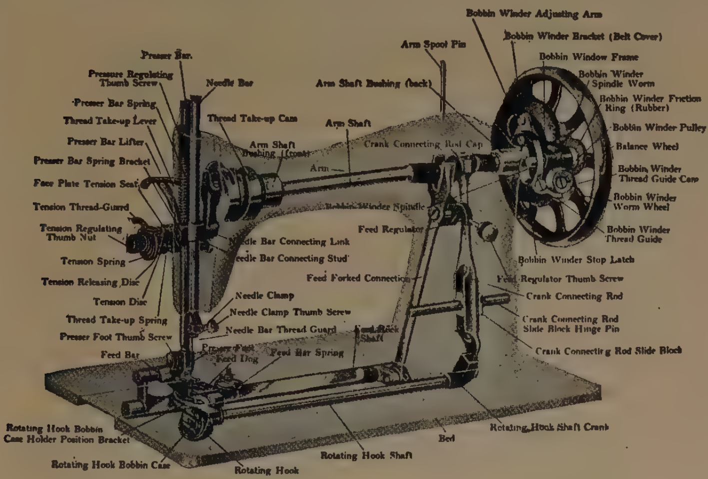


FIG. 22. — Mechanism of a rotary hook sewing machine.

How the stitch is made. Phantom Fig. 22 shows the working parts of the headpiece. The essentials for stitch making are the bobbin, bobbin case, and hook, below the bedplate, and the needle and the thread take-up lever above. Thread is carried below the bedplate by the needle; the bobbin with under thread must then pass through a loop in the needle or upper thread. This may be accomplished by a vibrating shuttle, an oscillating shuttle, or a rotating hook. The different steps in making a stitch, when the rotating hook is employed, are illustrated in Fig. 24. In step 1 the thread take-up lever is descending, thus loosening the thread at the needle. Just as the needle begins to rise, a loop of thread is formed. The point of the rotating hook now enters the loop of thread, which is carried around the stationary bobbin case

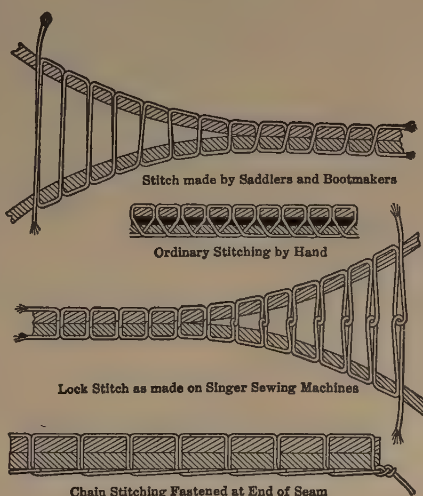


FIG. 23. — Types of stitches.

(step 2). In step 3 the hook has released the thread after having carried it around the under thread. The thread take-up lever now begins to draw the needle thread upward. Step 4 shows the completed stitch. The take-up lever has drawn the upper thread so that all slack is removed, and if the right tension is on the thread the upper and under threads of the lock stitch will be joined about halfway between the two surfaces of the materials which are being sewed.

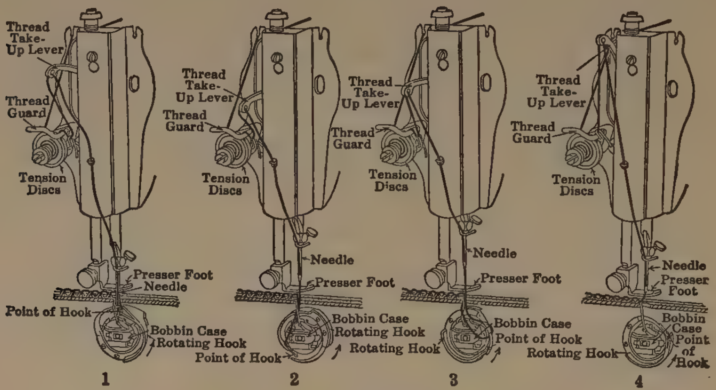


Fig. 24. — How the stitch is made.

No. 1 shows the first stage in stitch formation. The thread leading to the needle is loosened, because the thread take-up lever has begun its descent; the needle, after having descended to its lowest point, has been slightly raised and a loop of thread is thus formed which is immediately entered by the point of the hook, which rotates in one direction around the stationary bobbin case.

Loop of Needle Thread Enclosing Bobbin Case

No. 2 shows the second stage. The loop of needle thread has been taken by the point of the hook and is being passed around the bobbin case containing the bobbin of under thread, sufficient enlargement of the loop having been permitted by the descent of the thread take-up lever.

Under Thread Enclosed by Needle Thread

No. 3 shows the third stage. The loop of needle thread has been cast off from the hook, the under thread has been enclosed by the needle thread, and the thread take-up lever is being raised to tighten the stitch.

Stitch Completed

No. 4 shows the stitch completed. The thread take-up lever has been raised to its highest point, drawing the needle thread, together with the under thread, into the middle of the fabric, the two threads now being locked. The tension on the needle thread is regulated by the circular tension discs shown in the illustrations, and the tension on the under thread is regulated by a spring on the bobbin case.

Principles of cream separation. Since cream is less dense than milk, being composed of tiny globules of butterfat suspended in the milk, it gradually rises to the top. Gravity pulls down with more force upon the skim milk than upon the cream, and so the skim milk goes to the bottom of the vessel. However, the process is so slow that, unless the milk is quickly cooled and kept cold, it will sour before the separation is complete. A machine which separates the cream by mechanical means depends upon centrifugal action; it separates the cream com-

pletely before the milk has had time to cool, after being drawn from the cow. The cream from the separator makes butter of better quality and flavor than that produced by gravity separation. The principle of gravity separation is illustrated by shaking a teaspoonful of heavy lubricating oil in a large test tube with 30 cc. of water until thoroughly mixed. Allow this mixture to stand for a few minutes; the denser water seeks the bottom, while the less dense oil rises to the top.

The principle of centrifugal action may be illustrated by the following experiment. Fasten two strings to the opposite sides of the mouth of a Florence flask by a wire under the rim. Adjust this so that, after the strings are twisted tightly by turning the flask around many times, upon unwinding, the flask will be rotated rapidly and evenly. Fill the

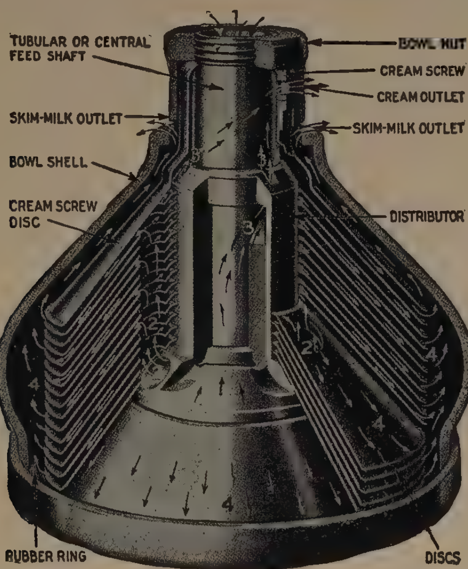


FIG. 25 — A section through the DeLaval Separator.

flask one-sixth full of water, and pour 30 cc. of mercury into it. Twist the string, and, as it unwinds, rotating the flask, notice how the mercury, the denser liquid, is thrown the farthest from the center and occupies the circumference of the flask at the place of its greatest diameter. If there were openings, the mercury would escape and be separated from the lighter water. By quite a different device, but upon the same principle, milk and cream are separated.

Cream separator. The milk is fed into the cream separator through a central pipe to a series of inverted conical plates, which in some machines are rotated at a speed of 10,000 revolutions per minute. As the

milk passes in thin layers over these cones, centrifugal force causes the denser of these, skim milk, to be thrown outward and downward, while the lighter cream is carried inward and upward, by the new supply of milk, which is constantly flowing into the separator. There are two outlets; while the machine is in operation, cream flows from one and skim milk from the other.

PROBLEMS

1. How much work is required to raise 10 gallons of water to an elevation of 20 ft.? (1 gal. water = 8 lb.) If the efficiency of a pump used to lift this water is 50 per cent, how much work must be expended in pumping?

2. The weight on a boiler safety valve is 2 lb. and is placed 1½ ft. from the fulcrum. What steam pressure, acting at a distance of 2 in. from the fulcrum, will this balance?

3. The large wheel of an egg beater has 56 cogs; the small wheel has but 7. How many times does the dasher revolve for each turn of the handle?

4. Make a diagram of a pulley, showing sheaves and number of ropes required to lift a weight of 400 lb. by applying a force of 80 lb.

5. A block and tackle has three strands of rope running to the movable block. In lifting a 300-lb. cake of ice 10 ft. it is found that 600 ft-lb. of work are done against friction. What is the efficiency of the block and tackle as a machine? What force (effort) must be used to lift the ice with this machine?

SUMMARY

1. Force is a push or a pull.

2. Work is performed when resistance is overcome through space.

3. Three kinds of resistance may oppose force. They are gravity, friction, and inertia.

4. Machines make it possible for us with small effort to overcome large resistances, but our effort must be carried through a greater distance than that through which the resistance is overcome. In all machines, effort × distance effort is applied = resistance × distance through which it is overcome.

5. In the lever, the simplest of all machines, the effort × effort arm = resistance × resistance arm. Arm is always the perpendicular distance from the line of direction of the force to the fulcrum, or the point about which the lever has a tendency to turn.

6. The mechanical advantage of a lever is the ratio of the effort arm to the resistance arm. In some levers there is a speed advantage:

$$E \times E \text{ speed} = R \times R \text{ speed}.$$

7. By considering the radii of wheel and axle as arms of a lever, all wheel and axle machines are resolved into a type of lever machine.

8. A fixed pulley gives no mechanical advantage. It is used in connection with movable pulleys and makes it possible to change the direction of the effort applied. The mechanical advantage of a movable pulley equals the number of ropes which come from the movable block.

9. With the inclined plane, a given force acting parallel to the incline will, if friction be neglected, lift a weight as many times itself as the incline is times the vertical distance. Or, expressed in formula:

$$\text{Force} \times \text{distance (length of incline)} = \text{weight} \times \text{distance (vertical)}.$$

The screw is a spiral inclined plane.

10. The efficiency of a machine is the ratio of the useful work done by a machine to the work expended upon it. Friction is the main cause of low efficiency in machines. Ball or roller bearings and lubrication are means of reducing friction.

11. The vacuum cleaner is a device for reducing the pressure, so that atmospheric pressure can push the dust and dirt into a container which holds the dirt but allows the air to escape. The degree of vacuum determines how effectively the machine cleans, but a vacuum greater than $3\frac{1}{2}$ inches of mercury wears carpets severely and, by causing the cleaner to cling tightly, makes it difficult to move the machine over the carpet.

12. In the sewing machine, two threads are used. By means of a moving shuttle or hook, the under thread is looped around the upper thread to make each stitch. The advantage of the sewing machine lies in the saving of energy, in speed, and in the quality of work done.

13. The cream separator makes use of the principle of centrifugal action — namely, the denser particles are thrown outward in a rotating liquid.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Archimedes, maker of early machines.
2. Machines of great power.
3. Evolution of the modern sewing machine.
4. Determine the mechanical advantage of some simple machines.
5. Determine the efficiency of some simple machines.

CHAPTER III

THE AUTOMOBILE

The working parts of the automobile. The last quarter of a century has witnessed a very remarkable development in the automobile, which has come to be considered by many as an essential household machine. In spite of the large number of different makes and styles, all automobiles, with the exception of the relatively few electric and steam-driven cars, are alike in their fundamental features. The great majority of cars use gasoline for the motive power and require a gasoline engine. The working parts in every motor car have four important systems: the running gear or chassis; the power plant; the transmission mechanism; and the electric system.

The chassis. The frame of a car is a vital part, as it serves to connect motive and transmission parts and to support them and the body. The axles are joined to the frame through springs. The wheels support the axles and receive power from the transmission system. Wheel controls, such as the steering gear and the brake devices, are all parts of the chassis. The frame is of chrome-nickel steel, and the front axle is of vanadium steel. It is essential to use tough and unbreakable steel for many of the parts, for the sake of safety. In a horse-drawn vehicle the entire front axle turns in steering, but in the automobile a pivoted axle allows the wheels alone to turn instead of the entire axle. The turning is controlled by the steering wheel in the hands of the driver. The usual method of braking is to expand or tighten a brake band within or outside the brake drum, which is securely fastened to each of the four wheels.

The power plant. We may consider as belonging to the power plant the engine and those accessories which are essential to its proper working. This includes the gasoline supply system and the cooling system, in addition to the engine itself.

The gasoline supply system. The tank holding from 10 to 20 gallons is generally placed at the rear of the car and at a level lower than the engine. Most new cars now pump the gasoline directly to the carburetor, and the air passes through a cleaning filter and silencer before it reaches the mixing chamber of the carburetor. It takes about fifteen times as much air as gasoline by weight, and 9000 times as much air by volume, to make the best mixture. Without some device to

reduce the noise from the use of such a large volume of air, an objectionable whistle or roar often develops. The silencer is a type of muffler and in some types has felt pads to reduce the noise of the engine intake. The cleaner element is a metal gauze which filters out the dirt and dust.

The gasoline-air mixture. The mixture of gasoline vapor and air which enters the engine cylinder is prepared in the carburetor. The

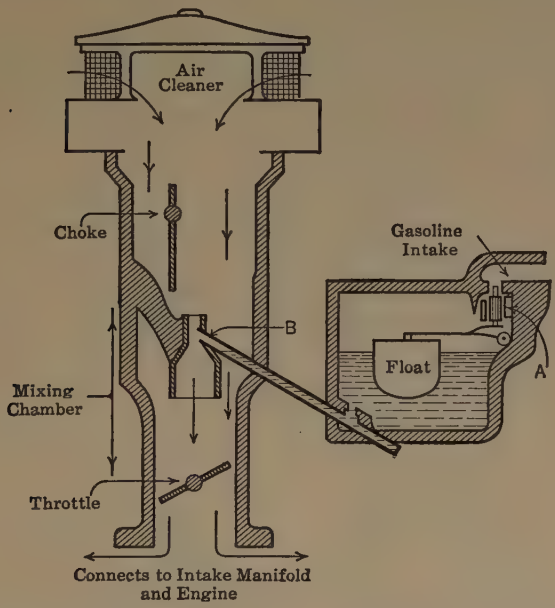


Fig. 26 —A downdraft carburetor. *A*. Inlet valve. *B*. Jet tube for gasoline discharge.

modern car uses filtered air, and gasoline is pumped from the rear storage tank directly to the carburetor. Figure 26 shows in simplified form a down-draft carburetor. Gasoline enters the float chamber from the pump through valve *A*. The float is lifted by the gasoline, and when the height is such that gasoline stands within $\frac{3}{8}$ inch of the top of the discharge tube *B*, the valve *A* is closed. If the float drops, the valve opens to allow more gasoline to enter. On the intake stroke of a cylinder of the engine a partial vacuum is produced in the intake manifold. The reduced pressure on the gasoline in tube *B* allows it to spurt out, being pushed by the greater air pressure on the gasoline in the float chamber. Air also rushes in through the filter and down the passage, mixing with the gasoline which vaporizes instantly. The intake manifold carries this gasoline-air mixture to the inlet valves of all the cylinders of the engine.

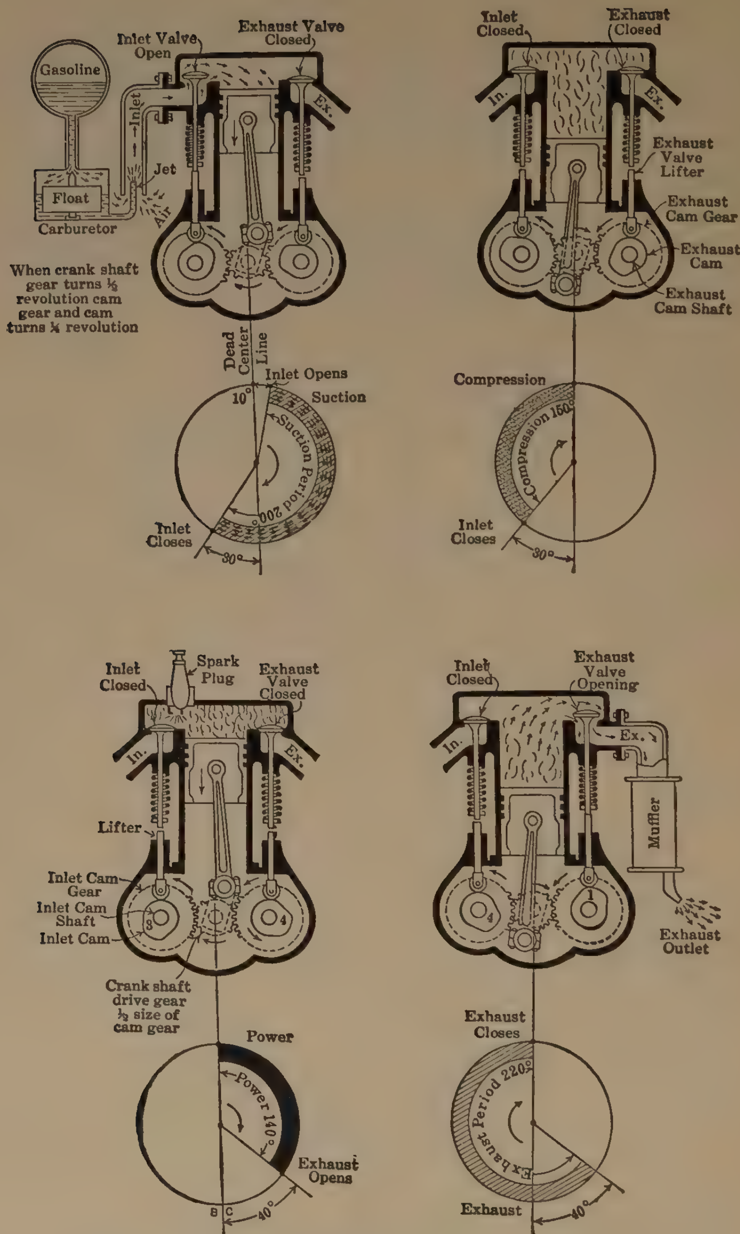


FIG. 27.—The four strokes of a four-cycle gasoline engine.

Control of the mixture. The driver of the car has two controls. The accelerator, whether by foot or hand, operates the throttle. Opening the throttle allows more fuel mixture to pass to the engine and gives more power. When the engine is cold, it is well to enrich the mixture. The choke operates in either of two ways or by a combination of both to increase the percentage of gasoline in the mixture. This may be done by injection of additional gasoline into the mixing chamber or by reducing the air intake. In the diagram only the latter is shown. The choke valve is turned like the damper in a stovepipe to reduce the current of gases.

Intake manifold. The intake manifold is the chamber in which the spray of gasoline from the jet tube of the carburetor becomes vapor and is mixed with air. It is joined to the inlet pipes of all the engine cylinders. The *throttle valve,* controlled by the foot accelerator and the hand lever on the steering wheel or dash, is so placed in the manifold that the quantity of "charge" entering the engine can easily be controlled. A partial vacuum is produced here at each opening of a cylinder intake valve.

Gasoline engines. The action of the gasoline engine depends upon expanding gases. Heat is produced by burning a gas inside the cylinder. By means of the carburetor, gasoline is changed to a vapor. This vapor mixed with air makes the "charge" of gasoline and air which enters the engine cylinder.

The four-cycle gas engine is the common one. Power is applied to the piston every fourth stroke, or once in two revolutions of the flywheel. The operation of the engine, Fig. 27, is as follows:

1. On the first — the *intake* or *charging* — stroke, the inlet valve is open. The moving piston tends to produce a vacuum in the cylinder. Outside air-pressure forces a charge of mixed gasoline vapor and air into the cylinder.

2. In the second — the *compression* — stroke, both valves are closed and the returning piston presses the gas mixture into a small space, greatly increasing its pressure.

3. In the third — the *power* — stroke, an electric spark ignites the compressed gas mixture. An explosion follows, with resulting high temperature, and expansion of gases in consequence. Both valves are closed, and the piston is forced out under great pressure. This motion is communicated to the flywheel, which stores up energy in its momentum, to carry the piston through the next three strokes in which no power is applied.

4. In the fourth — the *exhaust* — stroke, the inlet valve is closed and the outlet valve is open. The piston pushes the burned gases out of the

cylinder, after which the whole series of strokes, beginning with 1, is repeated.

The exhaust gas makes a loud explosive noise if discharged directly into the air. The noise is greatly reduced if the exhaust is discharged through a *muffler*. Sound can be greatly reduced in a muffler by dividing the exhaust gases and likewise the sound. One part of the sound travels through the long tube *A* and another part through the short tube *B*. These are of such lengths that, when the sound waves come together at *C*, they will be at opposite phase and will to a large degree cancel each other.

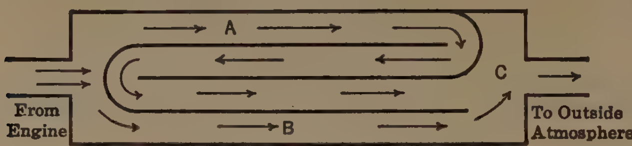


FIG. 28.—One type of muffler.

Number of cylinders. We have just seen what happens in one cylinder during a complete cycle. A similar cycle of strokes takes place in each cylinder. In a four-cylinder engine, four being the smallest number of cylinders which gives satisfactory service in an automobile, it is so arranged that the power strokes of the different cylinders follow in succession rather than that two or more occur at the same time. This gives a more uniform application of power. In Fig. 29 you will observe four bands; each one represents the strokes of a single cylinder. The inner band is for cylinder 1; the next, 2; the next, 4; and the outer one is for cylinder 3. The black represents the power stroke. There is practically a continuous power stroke, but there is no overlapping of power from any two cylinders. As the number of cylinders increases, there is more and more overlapping of the power strokes, which results in greater evenness in running and is a decided advantage in climbing hills and in running slowly in high gear in traffic.

Engine-cooling systems. Very high temperatures are developed by the burning gas in the cylinders — high enough to make the metal red hot unless the heat can be removed. Engines may be *air-cooled* or *water-cooled*. Cylinders of engines that are air-cooled are made in such form that they have a large radiating surface. This may be done by having flanges or by studding the surface with many projections. Much air is forced over these surfaces to remove the heat. Water-cooled engines have a water jacket surrounding the cylinders.

This jacket is connected to both the top and the bottom of a radiator, where the hot water may be cooled both by radiation and by contact with cold air, which is made to flow over the surfaces by means of a

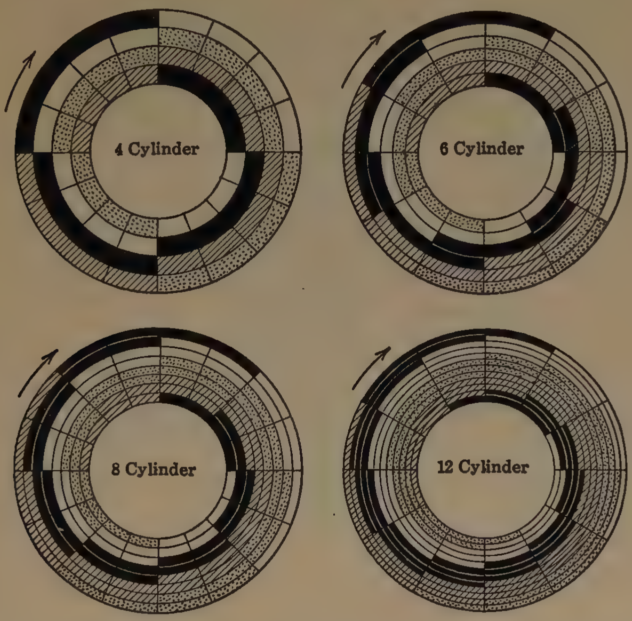


FIG. 29.—How an increase in the number of cylinders gives a more uniform application of power. The power strokes are represented in full black. Each circular band represents one cylinder.

fan. In freezing weather, alcohol, or alcohol and glycerin, or some commercial anti-freeze preparation, is mixed with the water to prevent freezing.

The driving mechanism of the automobile. How is the power of the engine transmitted to the car? It is a complicated process involving a whole group of devices which are included in the transmission mechanism. They are: clutch, gears, universal joint, propeller shaft, differential, and rear axle. The rear axle turns the wheels, which, by means of the road resistance, carry the car forward.

Friction clutch. Of several types of clutches, the *friction clutch* is most common. The friction may be between plates, as in the *disc* clutch, or between the surfaces of a cone and a conical recess in the flywheel, as in the *cone* clutch.

In the cone clutch the flywheel of the engine has a conical recess in its rear side. A metal cone, faced with leather and attached to the

driving shaft, fits into this recess. Foot pressure on the clutch pedal releases the cone so that the engine flywheel may revolve without

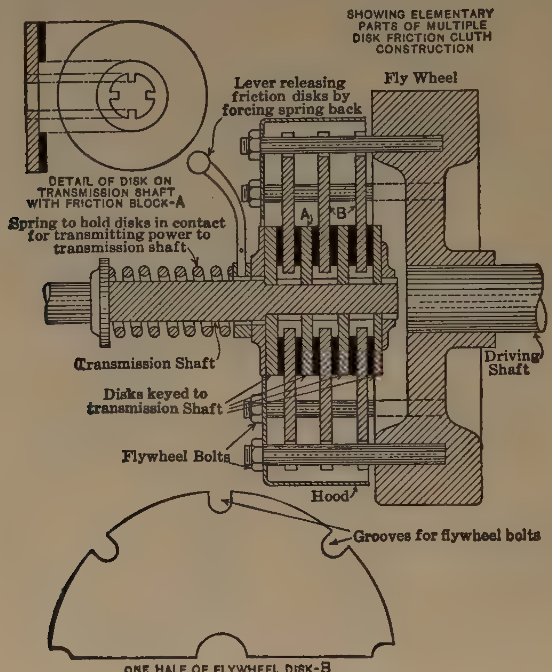


Fig. 30.—The disc clutch.

moving the driving shaft. When the foot pressure is released a powerful spring presses the cone into the flywheel recess so firmly that the two revolve together. In the disc clutch the flywheel has attached to it a series of driving discs. An equal number of discs, attached to the driving shaft, are pressed against these by a spring.

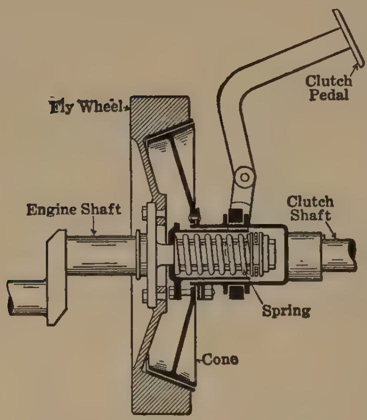


Fig. 31.—The cone clutch.

Power transmitted to wheels. By a system of interchanging gears, the driving shaft transmits motion to the propeller shaft. These gears are so arranged that different forward speeds may be obtained or reverse motion produced. The propeller shaft turns a geared wheel in the *differential*, which transmits the motion to the

wheels of the automobile. The differential contains gears so arranged that one rear wheel may turn independently of the other. This makes it possible, in moving around a curve, for the outside wheel, which goes a greater distance, to move faster than the inside wheel.

Electricity in the automobile. Electricity is used in the automobile to set off the charge in the engine, to light the lamps, to operate the starter, and to sound the horn. The source of current may be a generator, storage cells, or dry cells. One form of generator, the magneto, supplies high-tension electricity to ignite the charge in the engine cylinders. When a low-tension magneto is used the current must be stepped-up by a coil. Battery current through a step-up induction coil will give the necessary pressure to produce a good spark and is used in many makes of cars.

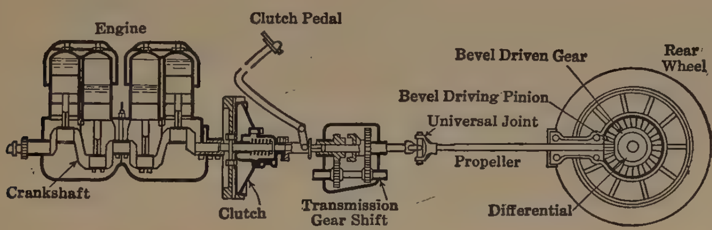


Fig. 32. — Transmission system. How power is carried from engine to wheel.

Generator and starter. All cars have a generator which is driven by the engine. The electricity is used to charge a storage battery. Since generators can also be operated as motors, when the engine is not running, current from the battery can be sent to the generator, which is thus made to act as a motor. By proper gear connection it will turn the engine shaft and so start the engine. An automatic release throws it out of gear as soon as the engine starts, and it then becomes a generator again. In many cars a motor, separate from the generator, is installed to start the car.

Ignition systems. An electric spark within the engine cylinders is employed to cause the gas mixture to explode. High-potential electric current is required for this. The high-tension magneto is a generator with special wiring to produce current at sufficiently high potential to give the required spark. When storage battery, dry cell, low-tension generator, or magneto current is used, it must be stepped-up to a higher voltage by means of an induction coil.

Each cylinder must receive its spark in its turn. It is necessary, therefore, to have a distributing device which sends the high-tension current to the cylinders in the order of firing. A cable with heavy

rubber insulation goes from the distributor to each spark plug. Only one wire to each is needed, because the return is grounded. In a four-cylinder engine the firing order is 1, 2, 4, 3; cylinder 1 is the one forward, nearest the radiator. In a six-cylinder engine the firing order may be 1, 4, 2, 6, 3, 5, or 1, 5, 3, 6, 2, 4. The spark is produced at the right time in each cylinder by the *automatic timing device.*

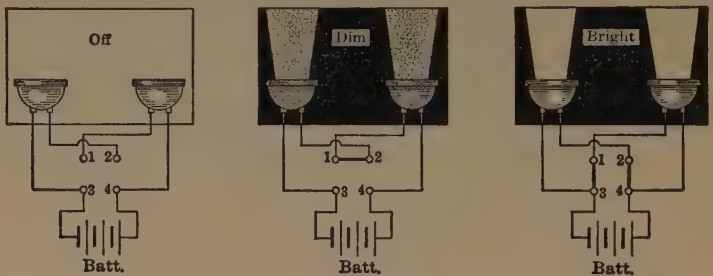


FIG. 33. — One way of dimming headlights. How the switch changes the current to vary the light intensity. Explain the diagrams.

Electric lighting system. In lighting systems employing the storage battery, the most common voltage is 6 volts. The low voltage allows the use of a larger and stronger filament in the lamp. There are two systems of wiring, *one-wire* and *two-wire.* In the one-wire system the

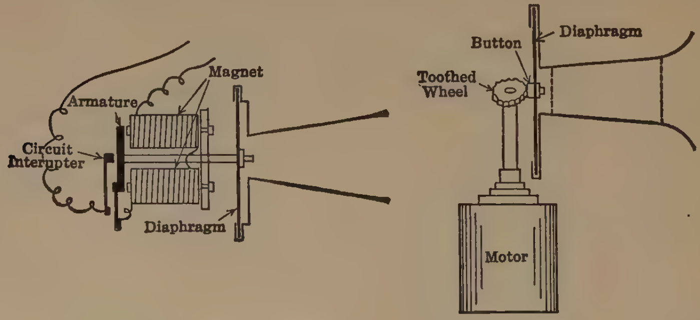


FIG. 34. — *A.* The electric vibrator horn. *B.* The electric motor horn.

metal framework of the car is a *ground,* and returns the current as does the second wire in the two-wire system. The lamps are joined in parallel but, if a rear *stop* light is provided it is well to have that in series with a 2-candlepower lamp on the dash, as then the driver can tell whether or not the rear light is on, since one will not be lighted without the other.

Electric horn. Electric horns are made in two types. One, shown in Fig. 34 *A,* is operated on the principle of the electric bell, but with the moving armature causing vibration in a diaphragm rather than

striking a gong. The other has an electric motor which drives a toothed wheel against a button on the diaphragm, thus setting it into vibration, Fig. 34 *B*.

The storage battery. The common automobile storage battery is composed of three cells. Each cell contains lead plates in a solution of sulfuric acid. When the battery is charged, the negative plate is lead

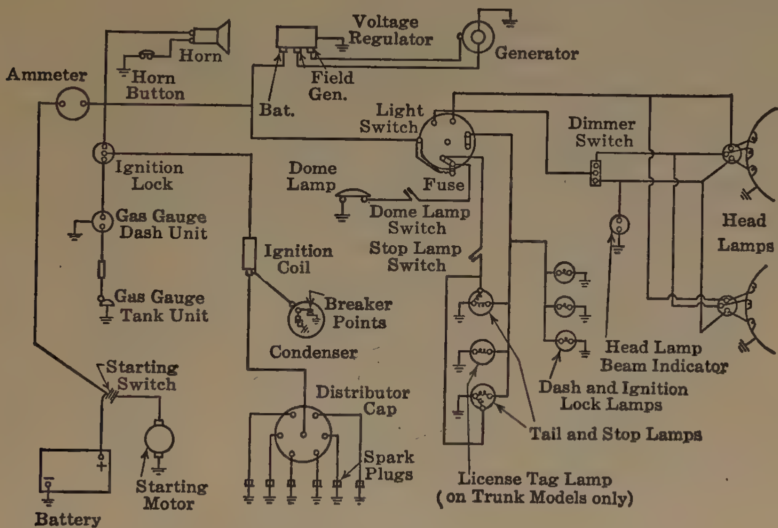


FIG. 35.—The electric system of a passenger automobile.

and the positive plate has a coating of lead peroxide on the surface and in the pores prepared to hold it. When the battery is supplying current for use, the reverse chemical action goes on, by which the lead peroxide reduces to a lower oxide. Each cell gives 2 volts. A 6-volt battery, then, must have three cells. The quantity of current the battery can give, after being charged, depends upon its size. Its capacity is indicated by the number of ampere-hours it will give. A 100-ampere-hour battery will give 100 amperes for 1 hour or 25 amperes for 4 hours. It is not well, however, to discharge a lead storage battery completely. The usual method of testing the condition of the battery is to determine the specific gravity of the acid solution. When the battery is fully charged, the acid solution has a specific gravity of 1.28 to 1.3. The hydrometer scale is based upon pure water as 1000. Hence a fully charged battery shows by hydrometer test 1280 to 1300; half charged is 1215 and discharged or "empty" is 1140. The plates must be kept covered with liquid by adding distilled water or rain water at intervals. If the battery is idle, it should be charged

every two weeks. This may be done by running the engine of the car for an hour, at a speed equivalent to 20 miles an hour on the road. If the car is located where the engine cannot be run and it is not desired to remove the battery, one of the many small battery chargers should be used. This can be attached to the electric-light socket and the battery charged overnight every two weeks. Frequent recharging of an idle battery is necessary, as without this precaution it will run down and the plates become so coated with lead sulfate that it will be worthless. A fully charged battery will not freeze at —80° F. At hydrometer test, 1200, it freezes only at —16° F., but when discharged to 1140, it freezes at —10° F.

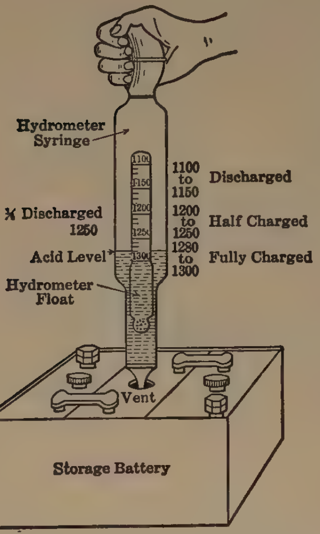


Fig. 36.—Testing the battery with a hydrometer.

"Pick-up" distance at night. The distance at which a person in front of the car can be seen at night depends upon the background, the color of his clothing, light glare, and the candlepower of the headlights. The headlights on many cars are so blinding that for a moment they completely destroy one's vision of objects ahead. Assume a dark background and absence of glare. Suppose, also, that a 21-candlepower lamp gives a beam candlepower of 50,000. A man dressed in dark blue is visible 900 feet away, one in medium color 1100 feet away, and one in white over 1500 feet away. If the adjustment of the lamp is poor or if the reflector surface is dusty or corroded, the beam candlepower may not be more than 15,000 candles. Under such conditions the pick-up distance is materially reduced. It must also be borne in mind that other headlights facing the driver reduce the pick-up distance enormously.

Braking distances. Consideration of the pick-up distance leads us to another very vital question: "In what distance can the car be stopped?" If a person is seen 100 feet in front of the car and there is no opportunity to turn out, can the car be stopped in time? It all depends upon the road condition, the brakes, and the speed of the car. Tests which have been made give very valuable information on this question. With poor brakes and a slippery road, a car going 20 miles per hour could not be stopped within a distance of 100 feet. Table I

gives the minimum stopping distance under these conditions: good brakes, level dry road, and driver reaction time of $\frac{1}{2}$ second.

The stopping distance must take into consideration not only the braking possibilities of the car but also the condition and grade of the road and the driver's reaction time. Obviously, other conditions being equal, the car will travel farther downhill than uphill after the brakes are applied. The reaction time varies considerably. The best results from tests show that about $\frac{2}{5}$ second must elapse after one sees the danger before the brake can be applied. Reaction time of $\frac{1}{2}$ second is fair. Many drivers have a reaction time of $\frac{3}{5}$ second or longer, and this is considered poor. If your reaction time is $\frac{1}{2}$ second and your speed is 50 miles per hour your car will travel 36 feet before you apply the brake. On a good dry level road if the brakes are in good condition it will travel an additional 125 feet, or altogether 161 feet, before the car can be stopped. A second of inattention would add 73 feet to this.

TABLE I

Relation of Braking Distance to Speed

Speed of Car		Distance, in Feet, that Car Must Travel before Stopping (Approx.). Assume four-wheel brakes	
Miles per Hour	Feet per Second (Approx.)	After Brakes Are Applied	Total after Driver's Reaction Time Is Added
20	29	20	35
25	37	31	50
30	44	45	67
35	51	61	87
40	60	80	110
45	66	101	134
50	73	125	161
60	90	180	225

Dangers from high speed. If you are traveling at 60 miles per hour, you cannot expect to stop in less than 225 feet, and probably it will be more than that. There is danger in passing another car. After getting alongside the car that you are trying to pass, you see a car coming towards you at high speed. You cannot complete the pass, neither can you slow down enough to retreat behind the car on your

side of the road. Another danger is on a curve. Centrifugal action comes into play here. At 50 miles per hour your curve-turning ability is only one-fourth that at 25 miles per hour; at 75 miles per hour it is only one-ninth that at 25 miles per hour. It is because of this physical law that so many fatal accidents occur at curves. Accidents at cross-roads can be reduced by reducing speed when nearing intersections.

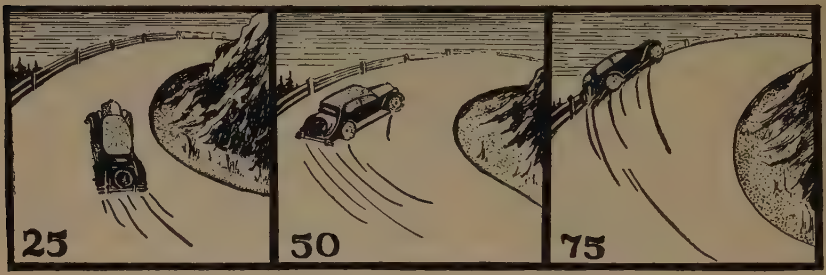


Fig. 37. — Centrifugal action increases the danger on curves.

Light for safe driving. The fact that the ratio of automobile accidents to the number of cars on the road increases greatly after dark is a reason why greater attention should be given to effective highway lighting and to the elimination of the headlight glare. Adequate street lighting is possible but too expensive except for thickly settled communities. Powerful sodium lamps give a very acceptable light. Reflecting buttons on rows of flexible posts along the road edge have been tried. These catch the light from the headlight and reflect it. The dimming of headlights upon approaching another car is a great help, but many who have a dimming switch fail to use it. Many schemes have been advanced to reduce the headlight glare. Perhaps the most promising is polaroid, which polarizes the light. If all the headlights have polaroid glass through which the light must pass, light coming to the oncoming driver will be polarized or will vibrate only in one plane. If the driver's windshield is polaroid glass with its axis set at right angles to that of the approaching headlights, then little if any light from that headlight will enter the driver's eyes. It is proposed, in practice, that the vibration planes of the polarizer in the headlights and windshields of all cars will be parallel and at an angle of 45 degrees to the roadway. Under this system, light from the driver's own headlights retains its original polarization when it reflects from the highway and other driving landmarks, and passes with great facility back through his own windshield. Therefore, the driver can see clearly the objects lighted by his own headlights.

SUMMARY

1. The essential parts of an automobile are: chassis, body, power plant, transmission mechanism, and an electric system.

2. The chassis includes the frame support, springs, axles, steering gear, and brakes.

3. The supply of gasoline is stored in a tank, from which it is brought to the carburetor, where it is vaporized. The gasoline vapor mixes with air in the intake manifold, and then this mixture, known as the " charge," enters the engine cylinder, where it is ignited by means of an electric spark.

4. The gasoline engine commonly used in the automobile is of the four-cycle type. The four strokes in this cylinder are as follows: *intake,* by which a charge is drawn into the cylinder; *compression,* by which the charge is compressed into a small volume; *power,* by which the charge is exploded by an electric spark at the terminals of the spark plug; *exhaust,* by which the burned gases are removed from the cylinder.

5. With a four-cylinder engine the power strokes follow each other in rotation. With six or more cylinders there is an overlapping of power strokes, and more even running results.

6. To remove the heat resulting from the exploding gas mixture, air or water is circulated around the engine cylinders.

7. The power of the engine is communicated to the rear wheels through the clutch, gears, propeller shaft, differential, and rear axle.

8. The friction clutch, joining the engine shaft to the transmission mechanism, is usually of the cone type or the disc type. In the cone clutch a conical member joined to the transmission is pressed into a conical recess of the flywheel by a powerful spring. In the disc clutch several discs on the transmission shaft are pressed by a spring against an equal number of discs attached to the surface of the flywheel.

9. The gear box holds gears so arranged that, through connection made by the gear-shift lever, different forward speeds and reverse motion are possible. When the lever is in neutral, no motion of the car results even though the engine is running and the clutch is in.

10. A generator is run by the engine, and its current charges the storage battery. Sometimes this generator also serves as a motor to start the engine, or a separate motor may be added for this purpose.

11. The spark to explode the gas mixture in the engine can be produced only by an electric current at high pressure. This high voltage may be secured by means of an induction coil which receives in its primary circuit the current from the battery. The secondary wires go to the spark plugs through the distributor.

12. The lights are connected to the battery through a switch on the dashboard. Lamps may be joined on either the one-wire or the two-wire system.

13. Electric horns are of two types, the vibrator and the motor.

14. The lead-plate storage battery has negative plates of lead and positive plates coated with lead peroxide, in dilute sulfuric acid. Charging consists in sending a direct current into the battery to produce lead peroxide on the positive and to remove oxygen from the negative plate. When the charging current is disconnected, and the circuit is closed, this chemical action is reversed, and an electric current results. The degree of charge is easily determined by means of a hydrometer.

15. The "pick-up" distance at night varies with the strength of the headlight and the color of the object.

16. Everyone ought to know the distance within which he can stop his car at different speeds. Brakes should be tested frequently to see that they are working properly.

17. In proportion to traffic, more accidents occur when streets are inadequately lighted at night.

18. Polaroid film seems to hold the solution for elimination of headlight glare.

19. Centrifugal action will not permit high speed around curves.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Development of the automobile industry in a quarter of a century.
2. Compare the advantages of six medium-priced cars.
3. Automobile accidents: the remedy.
4. Care of the battery.
5. Advantages of this year's models over those of last year.
6. Car heating and air conditioning.

CHAPTER IV

OUR USE OF HEAT

We seldom stop to think what a useful servant heat is in the household. We make our toast and coffee, have hot water always at hand, keep our rooms warm, and iron our clothes. Heat operates our thermostats, removes frost from the window panes, and makes our plants grow. Heat dries our clothes and cooks our foods. Our uses of heat depend upon the various effects that it produces. The addition of heat to matter is accompanied by increased molecular activity. This increased molecular energy gives rise to a variety of changes in matter. Four important effects are very common, namely: (1) a change in size, (2) a change in state, (3) a change in temperature, and (4) a change in composition (chemical change).

FIG. 38. — A fruit jar cover is loosened by holding it in hot water.

Change in size. It is believed that, when molecules vibrate with increased energy, they strike neighboring molecules with greater force and thus push them a little farther apart. This causes an increase in size, and we say that the body *expands.* Upon cooling it decreases in size, or *contracts.* When a glass stopper sticks in the neck of a glass bottle, it can be loosened by carefully warming the neck of the bottle. The neck gets larger and so loosens its grip on the stopper. When the cover on the fruit jar sticks it may be loosened by holding it a short time in hot water.

In making household repairs it is desired at times to remove a rusted screw or nut, but the screwdriver or wrench fails to give results. The ingenious household mechanic will place a hot iron against the head of the screw or will heat the nut, which can then be removed in the usual way. If nursing bottles are filled *full* of cold milk and put into the pasteurizing chamber, some of the milk will overflow when it is heated. Sometimes in hot weather we find the corks of bottles mysteriously removed. This is often caused by the heated gas inside pushing them out. In a similar way, gas bubbles in bread and cake increase in size

when heated and make the bread and cake light and porous. When the stove top gets red hot frequently, some of the parts are lengthened and put under too great strain, with the result that they warp and become permanently bent out of normal shape.

Strong heat applied quickly to an enamelware dish will cause the enamel to chip off, because the enamel conducts the heat less rapidly

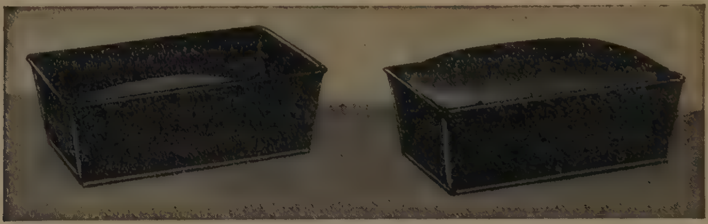


Fig. 39. — Bread is made "light" by the production of gas in it and by the expansion of the gas.

and so does not expand as quickly as the iron. Unless a clock or watch has some expansion compensating device, it will need adjustment when changing from winter to summer temperatures, in order to keep correct time. The cement walk may buckle in hot weather, while cracks are made in ice and in the frozen ground in extremely cold weather. This effect of heat — *change in size* — is also utilized in the thermometer and the thermostat. Expansion must be considered in industries, as when wires are sealed into glass in making electric lamps. The value of expansion in nature, as an agent in making soil, is very great. Even the circulation of air and water in our systems of house heating, as well as the winds and storms outside our homes, depend indirectly upon this very important effect of heat.

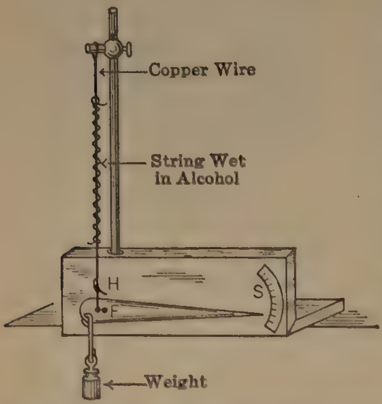


Fig. 40. — Why does the pointer rise on *S* when the wire is heated?

Demonstration of expansion of a solid. Suspend one end of a No. 14 or 16 bare copper wire 2 to 3 feet long from a support as in Fig. 40. Bend the lower end so that it connects with the hook (*H*) on the lower wooden pointer. The fulcrum about which the wire turns is just a bit to the right to the point of support, *H*. About an inch to the left, a weight of about 200 grams is attached so that it pulls downward. The pointer may be

8 to 10 inches long. A scale at its tip end shows its movement. Observe position of tip of pointer. Tie a piece of cotton string, wet with alcohol, around the copper wire, and set it on fire; or heat the wire with the gas flame. If the wire increases in length the weight will go lower, raising the tip of the pointer at *S*. What is the result of heating the wire? Do you observe that, as the wire cools, the pointer tip returns to its original position?

Careful experiments have shown that other metals also expand when heated, and contract when cooled, but that they do not expand the same amount for the same change in temperature. The *coefficient of linear expansion* is a technical term which indicates *that fraction of its length that a solid body expands for a rise in temperature of 1 degree.* The following table shows the relative expansions of a few solids.

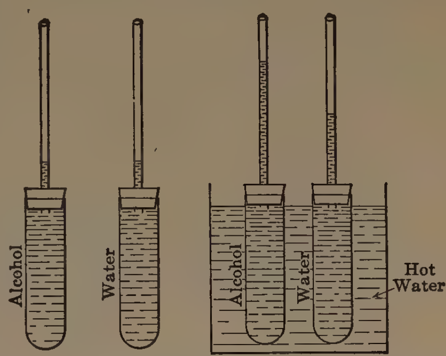


FIG. 41. — Alcohol expands more than water does under the same change in temperature.

TABLE II

COEFFICIENTS OF LINEAR EXPANSION

	For 1 Degree C.	For 1 Degree F.
Aluminum	0.000023	0.000013
Tin	0.000022	0.000012
Silver	0.000019	0.00001
Brass	0.000018	0.00001
Copper	0.000018	0.00001
Steel	0.000013	0.000007
Cast iron	0.000011	0.000006
Platinum	0.000009	0.000005
Glass	0.000009	0.000005
Glass — Pyrex	0.000003	0.0000016
Nickel-steel alloy	0.000009	0.000005
Quartz	0.0000005	0.0000003

Expansion of liquids. Fit two test tubes of the same size with rubber corks, each having a glass tube, 10 inches long, inserted in it as in Fig. 41. Fill one tube with colored water. Close with the stopper,

pressing it in until water stands about 2 inches above the stopper. Fill the other tube with colored alcohol. Close it, and press in the stopper until the alcohol stands at the same level above the stopper as the water does in the other tube. Immerse these two test tubes in a beaker of hot water. What is the result? Do the two liquids increase equally in volume for the same rise in temperature? If glycerin and gasoline are used, results parallel with those just seen will be obtained. It is thus

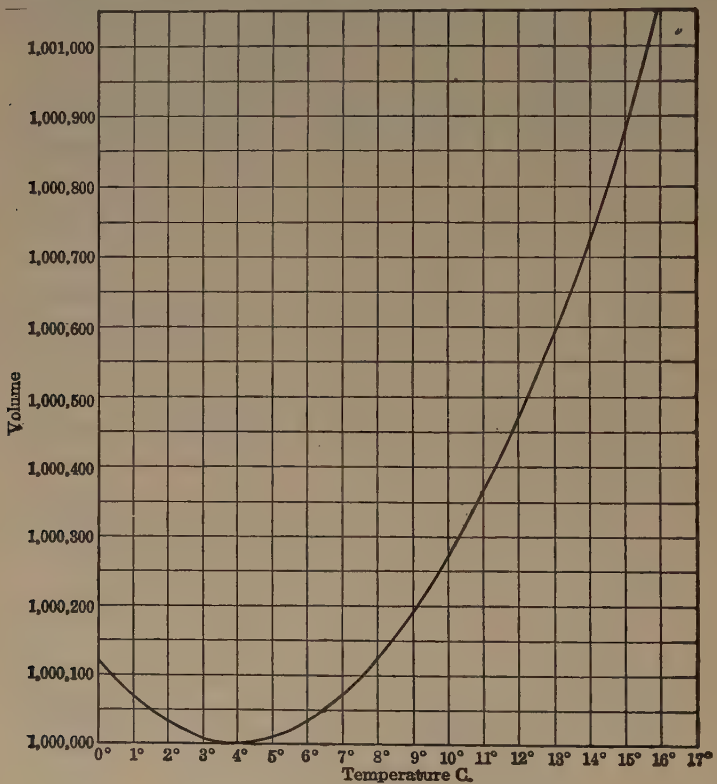


FIG. 42. — Expansion curve for water.

easy to demonstrate that, in general, *liquids expand when heated and contract when cooled,* and also that the *amount* of expansion for a given change in temperature *depends upon the liquid* used, being greater for alcohol, kerosene, and gasoline than it is for water.

There is often considerable variation in the expansion of the same liquid at different temperatures. This fact, illustrated for water, is well shown in Fig. 42 above. Here, unexpectedly, we find that water contracts when heated from 32° F. to about 39° F. (0° C. to 4° C.) and then expands, though not uniformly, at higher temperatures.

Will gases expand? After seeing that some solids and liquids expand when heated, we may wonder whether gases expand similarly. Experiment will show us. A large glass bulb, with a long, slender tube attached, is held with the open end of the tube under water, as in Fig. 43.

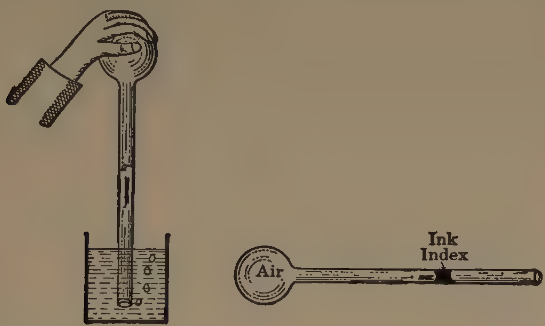


FIG. 43.—Expansion and contraction of a gas under changes of temperature.

Since the bulb and tube at the start are full of air, if the air expands upon being heated it must escape through the water and we shall see the bubbles. Warm the bulb with the palm of the hand. The escaping bubbles prove that the air expands when heated. If we use ink instead of water and let the air cool in the bulb after heating, we find that the ink follows the contracting air up the tube. If we warm the air again, we see that, as it expands, it exerts greater pressure and pushes the ink down the tube. As the air cools and contracts its pressure is less, and the ink rises again. It has been found that *all gases expand and contract to just the same extent as air does* under the same changes of temperature.

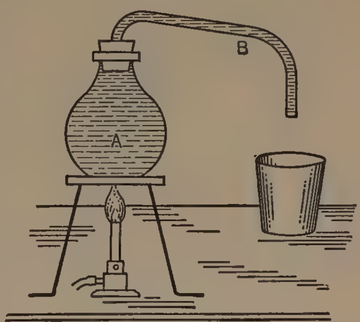


FIG. 44.—Expansion of water lowers its density.

In cooking, air is frequently used to secure lightness. For example, air beaten into pie crust expands in baking. If *cold* air, rather than *warm* air, is beaten in, as much as a 5 per cent increase in volume may be secured.

Density is changed by expansion. Density is the *weight of a unit volume of a substance.* A flask and tube shown in the drawing if filled with cold water will have a certain weight. If the flask is heated for 3 to 5 minutes, some water will drop from the end of the tube. The

flask and tube are still filled with water, but the weight of the water left is less. This volume of water is no less, but the weight of the same volume is less when hot than when cold. Therefore the density of hot water is less than that of cold water.

If we have two inverted cardboard boxes exactly balanced from a delicately pivoted rod and warm the air in one box, we can see whether it will still balance the box of cold air. A lighted candle is placed under box *A* to warm the air in that box. Remove the candle. Thermome-

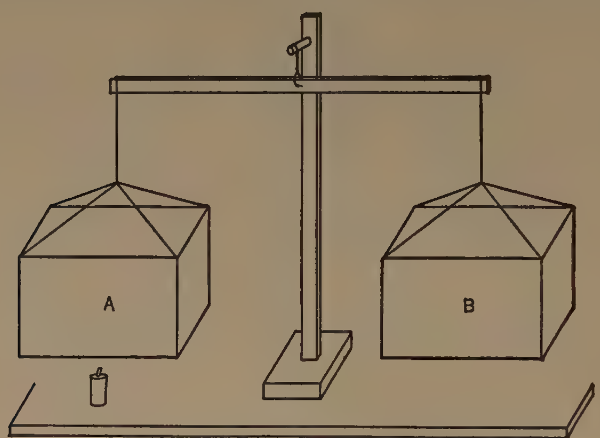


FIG. 45. — Expansion of a gas lowers its density.

ters may be used to indicate the differences in temperature, and the disturbed balance proves that the box of warm air, *A*, is lighter than the box of cold air, *B*. Change the candle. Put it under *B*. Result? Important applications are made of this change in density of bodies by heat.

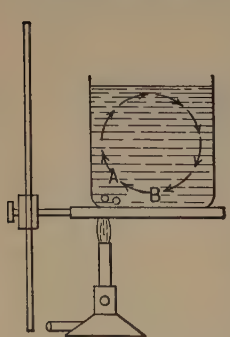


FIG. 46. — Convection currents in water.

Convection currents the result of expansion. One of the most important results of expansion is the creation of *convection currents*. Convection currents always occur when *a part* of a body of liquid or gas changes in density. We can easily make these currents visible. Let us drop a few crystals of potassium permanganate down the side of a beaker of water and place a Bunsen-burner flame directly under the crystals as in Fig. 46. The crystals slowly dissolve and color the water. If the water about the crystals moves, we can see this movement because all the water passing over the crystals becomes colored. Immediately after the application of heat we see currents

of water rising from the place where heat is applied. This stream of rising water broadens, moves across the top, and then sinks, as suggested by the arrows. After a time the colored water is thoroughly diffused, and since the colored water is the heated water, we may reason that the water in the entire vessel eventually becomes hot chiefly through the movement of these convection currents.

Since water expands when heated, a cubic inch of hot water weighs less than a cubic inch of cold water. *Weight,* as you doubtless know, is the measure of the force of gravity, or the force that is pulling all objects on the earth toward the center of the earth. If you compare the weight of a cubic inch of water at A — warm, expanded, and less dense water — with that of a cubic inch of water at B, which is cold and not expanded, it is apparent that the water at B is heavier than that at A. In other words, B has *more weight* than A, and will accordingly be pulled toward the earth with greater force. As a result, the cold water takes the lowest place in the beaker, and, as it flows in under the warm water at A, it lifts or pushes it upward. Then the water which has lifted A in turn becomes heated, and other cold water comes in and pushes it upward. This process continues without interruption until all the water is of the same temperature. The ascending hot water mingles with colder water, which is warmed by it.

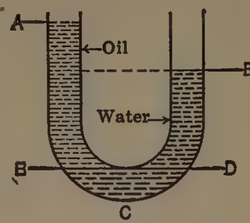


FIG. 47. — The denser water pushes the lighter oil to a higher level.

Possibly an analogy will make this process of convection clearer. You know that water is denser than oil. What will happen if you pour water into a dish of oil? Can you tell why the denser water goes to the bottom and pushes the lighter oil up? If we have water and oil in a U-tube, oil on one side and water on the other, the oil level will stand higher than the water level. If more water is poured in, the oil is lifted higher. Just so, cold air or cold water will flow in under warm air or warm water and lift them, starting convection currents.

Useful convection currents. Convection currents in air aid the burning candle. If we cover a burning candle with an inverted jar, we stop convection currents. The supply of oxygen is thus cut off and the candle goes out. All our fires must have convection currents to continue burning. Smoke passes up and out of chimneys in the process of convection. Convection currents in a kettle of water carry heat from the heated part of the kettle to water at a distance. This hastens the process of heating. We depend upon convection for natural ventilation and for circulation of air in the refrigerator. In our heating systems

hot water and hot air are used in convection currents to carry heat from the furnace to the rooms of the house. Large-scale convection gives us winds and ocean currents.

The importance in nature of the peculiar expansion of water shown in Fig. 42 may now be understood. If the expansion of water did not take place in this manner, when a body of water cooled on the surface, the colder surface water would continue to be denser until 32° F. (0° C.) was reached. In this event the surface water would continue to sink until the body of water was at 32° F. throughout, and the water might freeze solid from top to bottom. What actually happens, however, is that, after the water has cooled to 39° F. (4° C.), further cooling causes no contraction and therefore no increase in density but actually the water expands from 39° F. to 32° F. The layer of colder water remains on top and if cooled enough forms a sheet of surface ice.

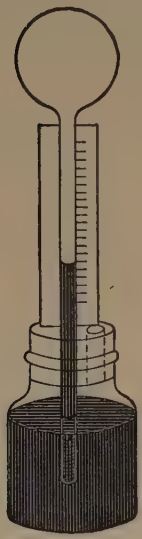


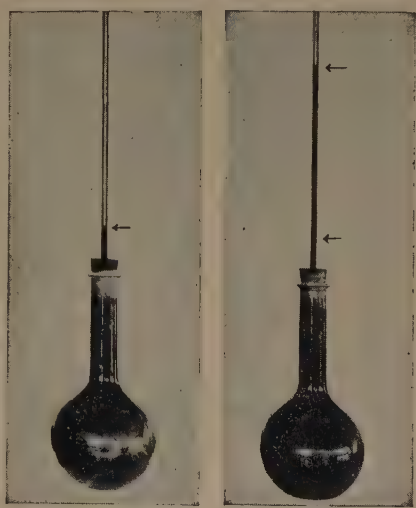
Fig. 48. — Air thermometer first used by Galileo.

Will hot water break glass? You know better than to heat water in an ordinary glass dish. Perhaps you have poured hot water into a glass and heard it crack. However, you bake in Pyrex glass vessels at a temperature much above that of boiling water. A demonstration will show you the results. Put ice cubes or very cold water into a small common cheap glass saucedish or thick glass jar, and place the dish or jar directly over the gas flame. In a few minutes the glass breaks and scatters fragments around. Repeat the experiment using Pyrex glass. This time the water may be heated to boiling and no dish is broken. The secret of this is that the common glass expands three times as much as the Pyrex glass. Glass is a poor conductor of heat. Heat applied to the outside of the vessel causes the outside to increase greatly in size while little heat has come through to the inside to cause the inside to expand. This puts great strain upon the glass, which is very brittle, and causes it to crack. The low expansion of Pyrex is due to the materials used in its manufacture.

Change in temperature. Temperature means the *degree or intensity of heat.* There was no instrument in the world for measuring temperature until a hundred years after Columbus discovered America. It was then that Galileo, an Italian scientist, invented an air thermometer. This consisted of a hollow glass ball and tube. The open end of the tube extended into a liquid. The air in the bulb was heated

until some escaped. Then the liquid came part way up the tube when cooled to its former temperature. Now when warmed the liquid would fall, and when cooled it would rise. The action was due to the expansion and contraction of the air in the glass bulb. A scale behind the tube was used for noting changes in reading.

How thermometers indicate temperature. Two effects of heat — *a rise in temperature* and *expansion* — are closely associated, and it is the dependence of one of these upon the other that makes it possible to determine one by measuring the other. In general, as the temperature of a body rises the body expands. Any substance which expands uniformly with an increase in temperature may be used to indicate temperature. Let us illustrate the action of a thermometer by means of a flask full of water, with a stopper and a glass tube rising 10 inches above it, as shown in Fig. 49. With colored water it will be more easily seen. As the stopper is pressed in, see that the liquid stands about 2 inches above the stopper in the tube. Fasten a piece of white paper back of the tube, and mark the level of the water. If, when the flask is heated, it grows larger, what will happen? Will the water rise or fall in the tube? You are right, it will fall. Now watch carefully as the flask is set in a basin of hot water (180° F.). As you expected, the water first drops in the tube, proving that the flask was made larger; but look again, and see what is happening. The water now rises in the tube even higher than it stood originally. Does the flask grow smaller? No. Then what is the explanation? Could expansion give the effect we have just seen? We see that it could, if we but note that the water must expand more than the glass does. The glass increased in size first because all the heat the water receives must come through the glass. Action similar to this takes place in the common mercury thermometer. The *apparent expansion* in a mercury thermometer is but five-sixths of the *real expansion*. This is because of the increase in size of the ther-



A B

Fig. 49. — Expansion of water. *A*. At room temperature. *B*. Result of placing flask in hot water for one minute.

mometer bulb and tube. By agreeing on some unit, and preparing a scale for measuring the apparent increase in size, it is possible to obtain an accurate measurement of temperature.

Liquids for thermometer fillers. We have just used water in our demonstration thermometer, but there are serious objections to it in a practical thermometer. It freezes at a much higher temperature than we have in our cold winters, and it boils at a lower temperature than we need for baking or candy making. Another property that makes water unsuitable for measuring temperature is its irregular expansion. Its coefficient of cubical expansion varies from 0.000053 to 0.000059, depending upon its temperature. Study of the expansion curve for water in Fig. 42 also shows that, in warming from 0° C. to 4° C. (32° F. to 39° F.), water contracts, and then expands upon a further increase in temperature. Its value at 2° C. would be practically the same as at 6° C. In fact, for all temperatures below 9° C. there would be uncertainty in regard to what the reading indicated.

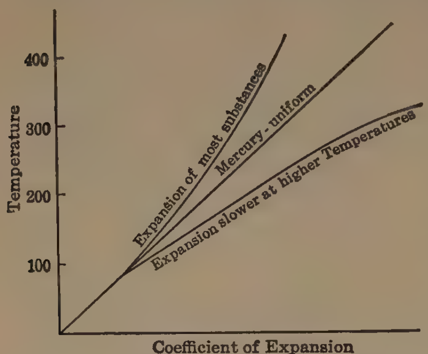


FIG. 50. — Mercury expands uniformly.

Two liquids, mercury and alcohol, have proved their usefulness in the thermometer. Mercury is best adapted for our common thermometers, for several reasons. It expands more uniformly at different temperatures than most liquids, Fig. 50, and it has an extensive range between its freezing point (—39° F.) and its boiling point (675° F.). It is a metal, and so a good conductor of heat. In being warmed 33 degrees, it absorbs only as much heat as the same weight of water in being warmed 1 degree. For these reasons it responds quickly to changes in temperature. Mercury is opaque and therefore easily visible.

The blue and red liquids in common thermometers are usually alcohol. The coefficient of expansion of alcohol increases with a rise in temperature, and for this reason alcohol thermometers are usually less accurate than mercury thermometers. Since alcohol boils below the boiling temperature of water, it is not suitable for thermometers for measuring the temperatures involved in many household processes. It does have a distinct advantage over mercury, however, for low temperatures. In our northern states mercury freezes in winter, but nowhere on the earth does natural cold ever reach the freezing point of alcohol.

Oven thermometers. Two types of thermometers are used on oven doors to indicate the temperature within the oven. One of these is the mercury thermometer; the other makes use of the expansion of a metal, or more commonly, of two metals joined in one bar. In the dial thermometer of this type, Fig. 51, a curved bar is made by fastening at short intervals a strip of brass to a strip of iron. The greater expansion of the brass, which is on the inside, makes the bar straighten a little. As it does so, the cord *C*, which makes a loop around the drum attached to the pointer, causes the pointer to move along the scale and indicate the temperature.

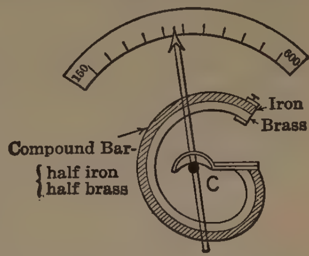


FIG. 51.—Dial thermometer on oven door.

Household thermometers. We are gradually outgrowing guesswork in regard to temperatures, but even now there is ample opportunity to replace temperature guesses by temperature facts in the household. In an efficient household of today the thermometer is a commonly used instrument. Most of our household thermometers are mercury thermometers, which differ from one another chiefly in the scales used. See illustrations on pages 57 and 58.

The clinical thermometer, Fig. 58, differs from the others in being self-registering. A constriction in the bore of the stem, just above the bulb, makes this registering possible. When the mercury expands, it is pushed through this narrow place into the stem, but when it cools and contracts the thread of mercury is broken by this constriction, and the mercury column is left in the tube registering the highest temperature which was reached. A quick-acting clinical thermometer has a very small bulb and will give maximum temperature in half a minute. A slow-acting clinical thermometer has a large bulb and requires three minutes.

TABLE III

SIGNIFICANCE OF THE READING OF A CLINICAL OR FEVER THERMOMETER

Below 98.6°, subnormal temperature,
98.6°, normal temperature,
99°–101°, slight fever,
101°–103°, moderate fever,
103°–105°, high fever,
105°–106°, very high fever — extremely dangerous.
When the temperature is over 101° it is best to call a physician.

Thermometers are delicate instruments, and must be used with care. The glass bulb is thin, to permit the quick conduction of heat. The

expansive force of mercury is very great; so great in fact that if the bulb is heated after the mercury column reaches the top of the bore, it will break the glass at its weakest point, which is the bulb.

High-pressure thermometers. Most thermometer tubes are sealed when the mercury nearly fills the tube. When the mercury contracts, a partial vacuum is left in the bore of the tube above the mercury. When thermometers are used to measure temperatures higher than the normal boiling point of mercury, the space above the mercury is filled with a gas, usually nitrogen or argon. As the mercury expands it compresses the gas, which in turn presses equally upon the mercury. Pressure prevents the mercury from boiling and so makes it possible to use mercury to measure temperatures higher than the normal boiling temperature of mercury. These thermometers must be made of strong glass to withstand this high pressure.

The Centigrade thermometer. In 1742, Celsius, a Swedish scientist, proposed a thermometer scale in which 0° should mark the boiling point of water and 100° the freezing point of water. These readings were later reversed by a French scientist, and the resulting thermometer is the **Centigrade thermometer,** which is in use in practically every part of the civilized world, except England and the United States. Even in these two countries the Centigrade thermometer is used in scientific work, and in other countries it is in use for both common and scientific temperature measurements. On the Centigrade scale, water freezes at 0° and boils at 100°. This is a more scientific scale than the awkward one devised by Fahrenheit.

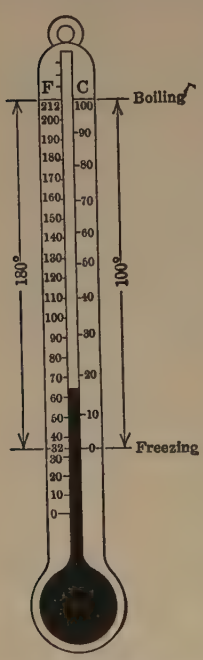


Fig. 52. — Comparison of Fahrenheit and Centigrade scales.

Comparison of Fahrenheit and Centigrade readings. The freezing point of water is 0° Centigrade and 32° Fahrenheit, Fig. 52. The boiling point of water is 100° Centigrade and 212° Fahrenheit. It is therefore seen that 1 Centigrade degree = 1.8 Fahrenheit degrees. By using these equivalents and remembering always that the freezing point of water is the common reckoning point for the two scales, it is an easy matter to calculate one scale reading from the other. For example, when the house thermometer reads 68° Fahrenheit, what would a Centigrade thermometer read in the same place? From 68° to the freezing point there are 68° − 32° = 36 Fahrenheit

degrees. 1 Centigrade degree = 1.8 Fahrenheit degree, and 36 ÷ 1.8 = 20° Centigrade. Hence the Fahrenheit reading of 68° is equivalent to a Centigrade reading of 20°.

Absolute zero. We already know that the heat in a body is due to the vibration of the molecules, and that as the molecules vibrate more slowly the body becomes cooler. It is believed that molecules possess heat as long as they vibrate, and that they can give out heat as long as they can "cool" or reduce their vibration rate. If a molecule ceases to vibrate, it has no heat. It is then at its lowest possible temperature, which is called **absolute zero.** Absolute zero is —273° C. and —459° F., and is believed to be the temperature of space which surrounds the earth and all the heavenly bodies.

PROBLEMS

1. Alcohol freezes at —114° C. What is its freezing point Fahrenheit?
2. Alcohol boils at 78° C. What is its boiling temperature Fahrenheit?
3. When the refrigerator temperature is 50° F., what would be its temperature Centigrade?
4. The normal body temperature is 98.6° F. What is it Centigrade?
5. What Centigrade reading corresponds to 0° F.?

Range of temperature. In the household the range of temperature is comparatively small, and thermometers with suitable scales are approximately as follows:

Weather	thermometer	—40° F. to 120° F.
Bath	"	50° F. to 120° F.
Milk	"	40° F. to 212° F.
Clinical	"	90° F. to 110° F.
Candy	"	120° F. to 390° F.
Oven	"	150° F. to 600° F.

In nature, however, we have a greater range of temperature, extending from about —90° F. in polar regions to above 120° F. in the desert, and to 3000° F. in the molten rock issuing from volcanic fissures. Since the time of Fahrenheit, besides the discovery of lower natural temperatures than he knew, man has produced vastly lower temperatures artificially. Scientists have produced a temperature within 1 degree of absolute zero. Some of our highest temperatures are produced in the electric furnace; but all temperatures used in our industries, and even the molten lavas of the earth, are cold compared with the temperature of the sun, which is estimated to be about 10,000° F. near the surface and many millions of degrees in its interior. Very high temperatures have been produced momentarily by passing an enormous amount of electrical energy through a very fine wire. A temperature of 50,000° F. is believed to have been produced in this way.

Change of state. Heat causes many solids to change to liquids and liquids to gases. Removal of heat causes these liquids to return to the solid state again, and the gases to return to liquids. We take advantage of this principle in many ways. We take heat from water to make ice cubes. By melting paraffin we can easily cover jelly in glasses and the paraffin quickly makes a solid covering which protects the jelly. Heat melts the shortening used in cooking or the fat for deep-fat frying. We use steam for cooking and to carry heat to steam radiators.

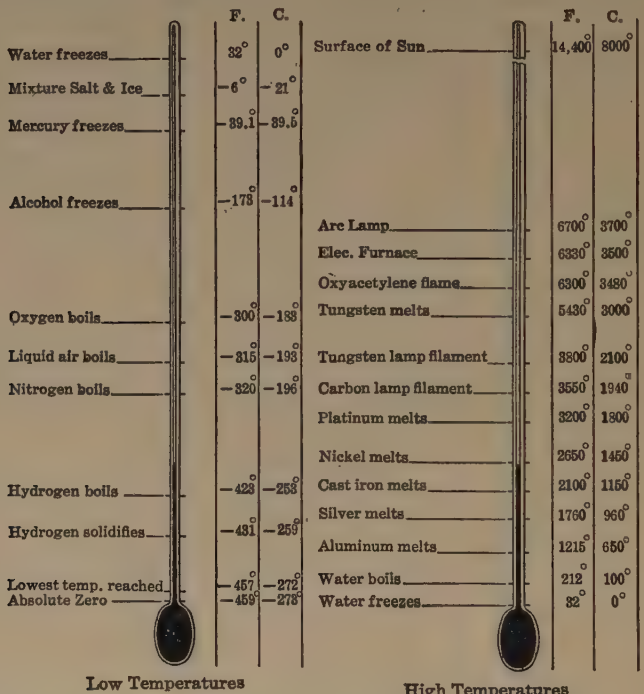


Fig. 53. — Range of temperatures from absolute zero to the temperature of the sun.

Clothes are dried by evaporation of the water. Damp clothing placed over the register or near the radiator makes use of heat in changing the water to a gas.

Chemical change. Many of our foods would not be relished today in a raw state. Long ago man acquired a liking for cooked foods. Some foods, however, are preferred raw. Many people object to cooked milk. Heat even below a boiling temperature coagulates the albumin, which forms a scum or skin on the surface. The browning of toast and the crust on the loaf of bread result from changing starch to dextrin by the action of heat. Heat increases the chemical action in baking

powder and promotes the action of yeast on sugar, setting free carbon dioxide. Heat also causes the bubbles of carbon dioxide to expand. In some commercial bakeries, carbon dioxide is admitted into a closed mixing tank which has all the other materials. The carbon dioxide is thoroughly mixed with the dough under pressure. When the dough is taken out and molded into loaves, the bubbles of gas expand under the reduced pressure and make it light. Heat of the oven causes expansion again in the process of baking.

The production of heat from fuel is a process in which heat starts and keeps chemical action going. But at the same time the chemical action produces a large amount of useful heat above what is necessary to keep up the burning of the fuel.

Undesirable chemical action in the household is also present, though this is not generally the direct result of the action of heat. Sulfur compounds in the air and sulfur in eggs and mustard darken silver by producing the brown silver sulfide. Rusting of the inside of an iron hot-water tank may color the water. Rust in time fills iron cold-water pipes so that the water pressure is greatly reduced.

QUESTIONS

1. In tuning a piano, the tension of a wire is increased to raise its pitch. What will be the effect of an increase in temperature on the pitch of a piano?
2. Why should a thick piece of glass crack more quickly than iron when suddenly heated? Give another reason besides brittleness.
3. When some woods burn in a fireplace, they snap loudly and throw off burning embers or sparks. Explain the reason for this.
4. Discuss the relation of energy to changes in state.

SUMMARY

1. Heat may cause four important changes in matter: a change in (1) size, (2) state, (3) temperature, and (4) composition.
2. Knowledge of expansion is helpful in many ways in the home.
3. Nearly all substances expand when heated and contract when cooled.
4. Expansion causes a decrease in density.
5. Convection currents result from a change in density caused by expansion. The denser cold liquid or gas, pulled by gravity, flows in under the lighter warm liquid or gas and lifts it. This explains why "hot air rises."
6. Convection currents are useful in many household processes.
7. Glass for baking does not break like common glass because of its small expansion rate.
8. The expansion of bodies is used in measuring temperature.

9. Galileo made the first thermometer. Fahrenheit devised the awkward scale of our common thermometer. The Centigrade scale is the one used in scientific work.

10. Expansion of solids, of liquids, or of gases may be used in measuring temperature.

11. Mercury is best adapted for measuring ordinary changes in temperature. Alcohol is best for low weather temperatures.

12. Mercury thermometers for measuring temperatures higher than the boiling point of mercury are made by enclosing gas under pressure in the stem above the mercury column.

13. Fahrenheit scale reading —32 = Centigrade scale reading × 1.8.

14. Absolute zero is the lowest conceivable temperature. It is the temperature at which the molecules of matter, possibly, cease to have any vibration.

15. When food is cooked the heat causes chemical changes which make it more palatable.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Some interesting results of expansion and contraction of bodies in nature.
2. How the engineer must take expansion into account.
3. Find out at what temperature hot water will crack thick glass.
4. Devise an experiment to measure the expansion of air when heated.
5. Special thermometers for special purposes.
6. Liquid air and low temperatures.
7. Make an alcohol thermometer.
8. Test readings of various home thermometers by comparison with a standard.

CHAPTER V

HOW HEAT IS MEASURED

Need of a heat measure. We buy coal by the ton, oil by the gallon, and gas by the cubic foot. These fuels give heat, but the heat itself cannot be measured in the same units that the fuels are measured in. As a rule, we do not attempt to measure the quantity of heat in the household. It is important, however, to have a measure of heat, for the value of a ton of coal depends on the quantity of heat it can give. Large users of coal purchase coal which has a specified heat-producing value. Likewise, in many states, legislation provides that gas companies produce gas which shall not, when burned, yield less than a specified minimum amount of heat per cubic foot. We study the heat-producing values of foods in making up our diet schedules. These heat values are given in heat units and are determined by experiments in which heat is measured. We do measure *temperature* in the home and this is important in *heat* measurement, but it is only one of the factors in the measurement of heat, as we shall soon learn.

"Hot" and "cold." In the household, in everyday life, we constantly need to know how "hot" or "cold" the room, the oven, a vessel of water, or some other object is. This condition of the room, the oven, or the vessel of water, we speak of as its **temperature.** The temperature of a body is its condition of "heat" or "cold." Since "cold" is only the absence of "heat," we may say that *temperature is the degree or intensity of heat.*

Our "feeling" unreliable in judging temperature. If we come into a room from out of doors on a very cold day, the room at first may seem very warm, although really too cold to remain in comfortably for a length of time. Similarly, when we first step out of doors from a warm room, the air may seem extremely cold. It is a common experience, when two persons enter the same room, that one will say, "It is too hot here," and the other will reply, "Do you think so? It feels too cool for me." An inactive person may feel chilly in air at 68° F., while one who comes from vigorous exercise may find the same air uncomfortably warm. From such experiences in everyday life, we must infer that our sensation of heat or cold is not a very reliable indication of the true temperature, since it is dependent on the condition of our body just before the sensation is experienced.

This we may illustrate to ourselves very readily as in Fig. 54. From the sensation of one hand, held for a time in a vessel of water at 40°, and then suddenly placed in a vessel at 70°, we should say that 70° is "very warm"; but if we test it with the other hand, which has been for a time in warm water at 110°, we should say that 70° is cold. When a piece of iron and a piece of cloth have been in a room for some time, we know that they must be at the same temperature as the air, but if we touch them both, the iron feels colder.* These experiments prove the unreliability of the sense of feeling in judging temperature.

Fig. 54. — Proving by experiment that "feeling" is unreliable in judging temperatures.

Thermometers. It is not now necessary to depend upon mere estimates of temperature. Very convenient and inexpensive thermometers indicate temperature accurately. These are made in various forms. Thus, the thermometer shown in Fig. 55 will tell the temperature of the living room or porch and will indicate whether there is danger of a frost at night. The scientific cook of today brings the oven for baking to a certain degree of heat, which is indicated by the oven thermometer, Fig. 56, and tells when the fireless radiator is at

* The reason that the iron feels colder than the cloth is this: The hand is warmer than the iron or the cloth and so loses heat to them, but because iron is a better conductor of heat than cloth, the heat received is carried away quickly by the iron and so more heat is taken from the hand. The piece of cloth directly under the hand gets warm, and because this heat is carried away slowly, less heat is taken from the hand. Hence the iron, because it removes more heat from the hand than the cloth does, actually makes the hand colder than the piece of cloth does.

the proper temperature by the thermometer shown in Fig. 57. The physician carries a little thermometer, Fig. 58, with which he can tell if the temperature of the body is subnormal or if there is fever. This is such an important device for indicating the presence of fever that, in the interest of good health, it ought to be a part of the equipment of every household. Many other special scales are used on thermometers

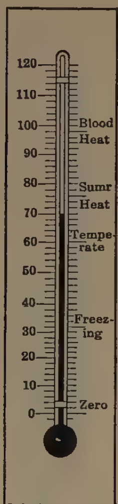


FIG. 55

FIG. 56

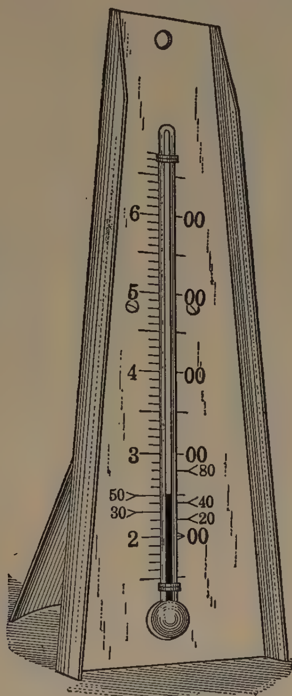


FIG. 57

FIG. 58

Kinds of thermometers: weather (55); oven (56); fireless radiator and oven (57); clinical (58).

for special purposes, as in the milk thermometer, the bath thermometer, the candy thermometer, and the incubator thermometer. These are illustrated in Fig. 59.

Distinction between heat and temperature. When heat is applied to a body, the temperature of that body rises. We may easily measure the rising temperature, but *this change in temperature is not a measure of the amount of heat added.* It is really surprising how few people can tell you the difference between *heat* and *temperature,* in spite of the fact that the distinction is extremely simple. Let us illustrate this distinction by means of an analogy. Sirup, as you know, is sweet

because of the sugar contained in it. Suppose we take a cupful of sirup from a gallon of sirup. We now have nearly a gallon in the can and, beside it, a cupful. Which of these has the greater quantity of

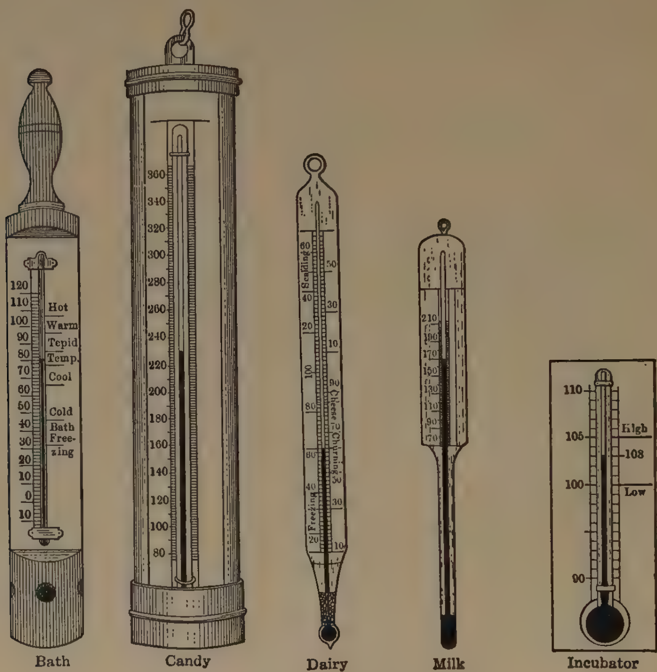


FIG. 59. — Household thermometers.

sugar in it? If we taste them, which will be the sweeter? You will all agree that both have the same degree of sweetness, but that the larger body has more sugar in it. Now suppose we have a gallon of

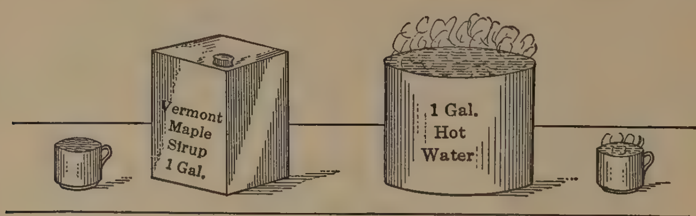


FIG. 60. — The sirup analogy.

boiling water and dip from it a cupful. The thermometer tells us that both have the same temperature, but do they have the same quantity of heat? If we leave them exposed to the air, the one that has the more

heat will cool more slowly. An hour later, which one will be the warmer? Experience tells us that a large body of water has more heat in it than a smaller body of water at the same temperature. *Temperature,* as we have said, *indicates simply the degree of heat, but does not measure the quantity of heat.*

A red hot nail is placed on a weighed block of ice. A cup of boiling water is poured slowly upon another block of ice of equal weight. The amount of ice melted is determined in each case. In one experiment, the nail at 900° melted ½ ounce of ice. The cup of water at 212° melted 12 ounces of ice. Did the iron or the water have the higher temperature? Did the iron or the water have the greater quantity of heat?

The measurement of heat. It is obvious from a little thought that heat has neither dimensions nor weight; therefore, we cannot measure it as we do common material things. We cannot have a "yard of heat," a "gallon of heat," or a "pound of heat." *Heat must be measured* as electricity or light is, *by its effects.*

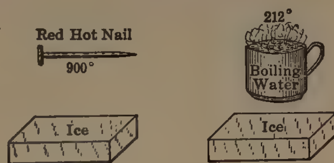


Fig. 61. — Does the body with the higher temperature have the more heat?

If we place a cupful of water and a pailful of water, both at 70° F., out-of-doors in zero weather, the water in the cup will freeze first, because it will be cooled to the freezing point first. Suppose the cupful of water and the pailful of water, both at 70° F., in vessels of the same material, are placed on the stove beside each other; which one will be warmed to 100° F. first? Experiments show that the pail of water is slower to cool and slower to warm to a given temperature. The reason of this is that, in cooling, the larger body has more heat to give out and, in warming, the addition to it of more heat is necessary to effect the same change in temperature. A hot-water bottle containing a quart of water at 180° F., in cooling to 60° F., will give out twice as much heat as a pint of water at 180° F. in cooling to 60° F. A pound of water at 180° F., in cooling to 60° F., will give out twice as much heat as a pound of water at 120° F. in cooling to 60° F. These facts indicate *two* of the *factors* which are involved in measuring heat absorbed or evolved when water is warmed or cooled. These factors are *weight* and *change in temperature.*

Now, heat applied to water raises its temperature, and it has been observed that the *same amount of heat applied to the same weight of water always gives the same rise in temperature.* Why not make use of this in measuring heat? This is just what is done, and *water* has been chosen as the *standard substance* in heat measurement.

Heat units. In making a unit for measuring the quantity of heat, three things are involved: (1) a standard substance; (2) its weight; (3) its change in temperature.

There are two systems of heat measurement, the English and the metric. Water is the standard substance in both systems. In the English system the unit is called the **British thermal unit** (B.t.u.). It is the *quantity of heat that will raise the temperature of* 1 *pound of water* 1 *degree Fahrenheit.* The metric unit, the one commonly used in science, is the **calorie.** This is the *amount of heat that will raise the temperature of* 1 *gram of water* 1 *degree Centigrade.* As the Centigrade degree is the scientist's unit of temperature, so the gram (gm.) is his unit of mass, or weight. A larger unit, the kilogram (kg.), equals 1000 grams. One pound equals 454 grams, and 1 kilogram equals 2.2 pounds. The Calorie (large calorie) is the *heat required to warm 1 kilogram of water* 1 *degree Centigrade.* It is equal to 1000 calories. Confusion has arisen from the use of the term calorie by some to designate the small calorie and by others to designate the large calorie. It is common practice to use the term calorie in connection with the energy value of foods when the large calorie is meant. Misunderstanding can be avoided by using the names *gram calorie* and *kilo-calorie.* One kilo-calorie is equivalent approximately to the heat required to warm 1 pound of water 4 degrees Fahrenheit. Hence one kilo-calorie (1000 gram calories) is equal to 4 B.t.u. One B.t.u. equals 252 gram calories.

PROBLEMS

1. In making coffee, how many B.t.u. are required to warm 1 qt. (2 lb.) of water from 50° F. to 212° F.?

2. How many calories must be given to 60 gm. of water to warm it from 20° C. to 100° C.?

3. When 4 lb. of water in a hot-water bag are cooled from 180° to 60° F., how much heat is liberated?

4. How much heat must be taken from 50 kg. water to cool it from 90° C. to 30° C.?

5. When two quantities of water at different temperatures are mixed, the warmer water loses and the cooler water gains heat, until all the water is at one temperature. What will be the final temperature when 2 lb. of water at 170° F. is mixed with 4 lb. of water at 50° F.?

Solution. We can resolve this into two simple problems: (1) How much heat will 2 lb. of water yield if cooled from 170° to 50°? $170 - 50 = 120°$ change of temperature. $120 \times 2 = 240$ B.t.u. (2) What change in temperature will 240 B.t.u. cause if applied to 6 lb. of water? $240 = 6x$, or $x = 40°$ change in temperature. Therefore, $50 + 40 = 90°$ F., the final temperature of the mixture.

6. If 150 gm. of water at 90° C. are mixed with 60 gm. of water at 20° C., what will be the resulting temperature of the mixture?

7. How many grams of milk at 5° C. must be poured into 200 gm. of coffee at 60° C. to cool it to 45° C.? Consider the quantity of heat required to change the temperature of milk and coffee the same as for water.

Heat capacity of different substances. In arriving at a way to measure heat we see that, with a standard substance, as water, two factors are required: *weight* and *change in temperature.* It takes 10 calories of heat to warm 1 gram of water 10 degrees Centigrade and 100 calories to warm 10 grams of water 10 degrees Centigrade.

In the household we need to warm many substances besides water, and so we are led to inquire whether all substances need the same amount of heat to produce the same rise in temperature. This question may easily be answered by an experiment. We may use hot water as the source of heat and then calculate the amount of heat is gives up.

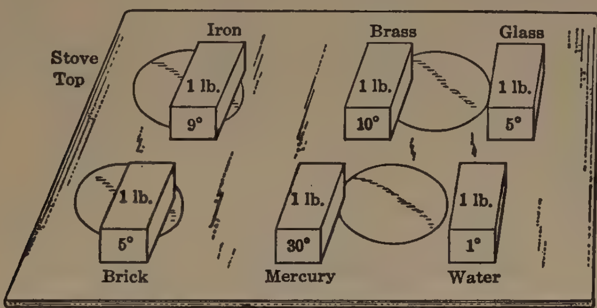


FIG. 62. — These bodies receive equal amounts of heat. Explain the different temperature changes.

For example, suppose 1 pound of water at 200° F. is poured into 1 pound of water at 100° F. and, after thoroughly stirring, the temperature of the mixture is 145° F. The fall in temperature of the hot water was 55° F. Hence 55 B.t.u. were given out by the water. The 1 pound of water, in warming from 100 to 145° F., must have absorbed 45 B.t.u. The difference between these two quantities, or 10 B.t.u., we may assume was absorbed by the containing vessel and surrounding air.

Let us now melt 2 pounds of lard in a dish like that which held the water, cool it to 100° F., pour into it 1 pound of water at 200° F., and mix the two thoroughly. If lard has the same heat capacity as water, the temperature of the mixture will be 145° F. as before. What do we find? Instead of 145° F. we find that the temperature of the mixture is 158° F. Since the lard is warmed to a higher temperature than the water was, and with less cooling of the hot water, we conclude that it does not require the same amount of heat to produce the same rise in

temperature in the lard that it does in the water. In other words, the heat capacity of lard is not the same as that of water.

Let us carry the calculation further. In cooling to 158° F. the hot water gave off 42 B.t.u. Let us allow a loss of 12 B.t.u. for warming the dish and the surrounding air. This is a little more than the warm water lost when poured into the cold water, but because of the higher temperature (158° instead of 145°) there would be a greater loss of heat. After taking away 12 B.t.u., 30 B.t.u. will be left for warming the lard. Since the lard was warmed 58°, the heat it absorbed in being warmed 1 degree is $30 \div 58 = 0.51$. It therefore requires 0.51 B.t.u. to warm 1 pound of lard 1 degree Fahrenheit, while it requires 1 B.t.u. to warm 1 pound of water 1 degree Fahrenheit. Hence, the heat capacity of lard is about one-half that of water.

And so it is with other substances. Copper holds only 0.093, and iron 0.12, as much heat as water under like conditions. Every substance has it own heat capacity. *Heat capacity* is the third and last factor necessary in order to make measurements of the quantity of heat involved in warming or cooling any substance other than the standard substance, water.

Specific heat. In making a comparison of heat capacities of different substances, it is convenient to specify their ability to absorb heat in terms of the heat-absorbing power of water. The heat capacity of a unit weight of a body is its **specific heat,** which is the ratio:

$$\frac{\text{Heat absorbed by 1 unit weight of given substance in being warmed 1 degree}}{\text{Heat absorbed by 1 unit weight of water in being warmed 1 degree}}$$

But, since 1 heat unit is always required to warm 1 unit of water 1 degree, we may define *specific heat* as *the number of heat units necessary to warm* 1 *unit weight of the substance* 1 *degree.* The heat capacity of lard was found to be 0.51 that of water; hence, the specific heat of lard is 0.51.

It requires 0.51 B.t.u. to warm 1 pound of lard 1 degree Fahrenheit, and it takes 0.51 calories to warm 1 gram of lard 1 degree Centigrade. That amount of heat which is gained by a body in being warmed is lost when the body is cooled through the same change in temperature. The specific heat of water is 1. It takes 100 calories to warm 25 grams of water 4 degrees Centigrade, and, when 25 grams of water are cooled 4 degrees Centigrade, 100 calories of heat are liberated.

The numerical value of the specific heat of a substance may easily be determined experimentally. Water is commonly taken as a convenient substance for measuring the quantity of heat. This method, known as the **method of mixtures,** is as follows: We may wish to find

the specific heat of aluminum. Two hundred grams of aluminum are warmed to 300° C., and immersed in 1000 grams of water at zero. The temperature of the water rises to 12° C. The water gained $1000 \times 12 = 12{,}000$ calories. This heat was lost by the aluminum in being cooled 288° C. One gram of aluminum, in cooling 1 degree, must have lost $\frac{12{,}000}{200 \times 288}$, or 0.21 calorie; hence the specific heat of aluminum is 0.21. In an exact determination a small allowance would be made for the heat absorbed by the containing vessel.

TABLE IV

Specific Heats

Liquids

Ammonia (liquid)	1.012	Mercury	0.033
Alcohol (ethyl)	0.550	Milk	0.940
Methanol (methyl alcohol)	0.590	Olive oil	0.310
Light cream	0.900	Paraffin oil	0.510
Heavy cream	0.700	Petroleum	0.460
Glycerin	0.550	Turpentine	0.459
Lard (melted)	0.510	Water	1.000

Gases (at constant pressure)

Air	0.238	Hydrogen	3.410
Ammonia (gas)	0.508	Nitrogen	0.244
Carbon dioxide	0.247	Oxygen	0.220
Carbon monoxide	0.242	Steam	0.480

Solids

Aluminum	0.212	Human body	0.830	Potato	0.800
Apples	0.910	Ice	0.505	Poultry	0.800
Beef (lean)	0.770	Iron (wrought)	0.113	Salt	0.170
Brass	0.094	Iron (cast)	0.130	Silver	0.056
Brick	0.195	Lard	0.350	Soapstone	0.210
Butter	0.600	Lead	0.031	Steel	0.120
Celery	0.960	Limestone	0.216	Stone (general)	0.210
Charcoal	0.242	Marble	0.216	Veal	0.700
Coal	0.204	Nickel	0.100	Wood: Birch	0.480
Copper	0.093	Plaster	0.200	Oak	0.570
Eggs	0.790	Platinum	0.032	Pine	0.467
Glass	0.190	Porcelain	0.260	Zinc	0.093

How specific heat is determined. When water at one temperature is mixed with a substance at a different temperature, the warmer body loses heat and the cooler gains heat. Except for the small amount of heat absorbed by the containing vessel, called a **calorimeter**, the heat lost by the warm body is taken by the cool body, and by a simple

calculation the specific heat of the body is determined. This is the *method of mixtures* previously described for finding the specific heat of melted lard and of aluminum.

If we wish to determine the specific heat of the solid lard, butter, or

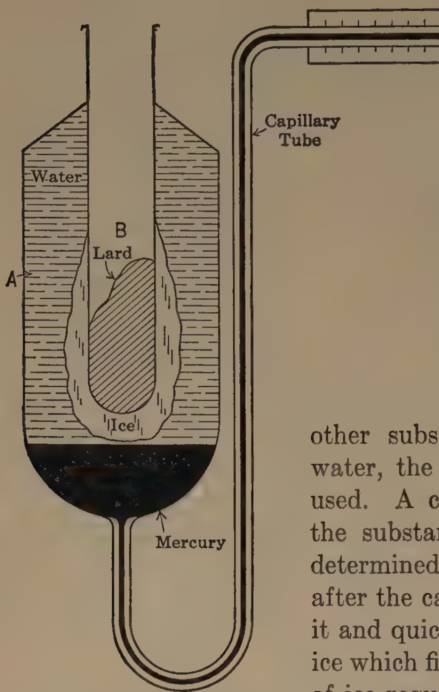


Fig. 64. — Bunsen ice calorimeter.

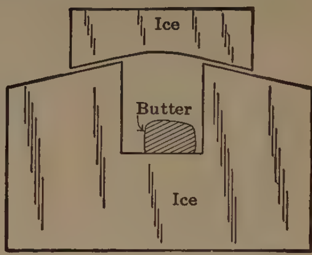


Fig. 63. — An ice calorimeter.

other substance which would melt in hot water, the **ice calorimeter**, Fig. 63, can be used. A cavity is made in a block of ice, the substance whose specific heat is to be determined has its temperature taken, and, after the cavity is wiped dry, is dropped into it and quickly covered with another block of ice which fits tightly over it. To melt 1 gram of ice requires 80 calories. Hence, from the amount of ice melted, determined by absorbing the water on a piece of cotton and weighing it, it is possible to calculate how much heat was given up, and so to find the specific heat.

Another method of finding the heat liberated in melting ice is by means of the **Bunsen ice calorimeter**, which is shown in Fig. 64. First, a part of the water in chamber *A* is frozen by a freezing mixture in *B*. The freezing mixture is removed and the substance whose specific heat is to be determined is heated and placed in *B*. As contraction occurs during the melting of ice, the mercury in the indicator tube is drawn back in the proportion to the amount of ice melted. The amount of ice melted gives data for calculating the heat lost by the body, and so the specific heat can be obtained.

Problem: How much heat will be required to warm 200 gm. of aluminum from 10° C. to 100° C.?

Solution: The specific heat of aluminum is 0.212.

Hence it takes 0.212 calorie to warm 1 gm. of aluminum 1 degree Centigrade.

$200 \times 0.212 = 42.4$ calories to warm 200 gm. 1 degree Centigrade.

And $42.4 \times 90 = 3816$ calories to warm 200 gm. aluminum from 10° C. to 100° C.

If we had 200 gm. of aluminum at 100° C., it would give up 3816 calories in cooling from 100° to 10°. From this we may deduce this formula:

$$\underset{\text{heat given out or heat absorbed}}{H} = \underset{\text{weight}}{W} \times \underset{\text{specific heat}}{\text{Sp. H.}} \times \underset{\text{change in temperature}}{\text{Ch. T.}}$$

PROBLEMS

1. A 7-lb. flatiron is heated to 490° F. How much heat will it lose in cooling to 300° F.?

2. How much heat is required to warm 2 lb. of lead from room temperature (70° F.) to its melting point (625° F.)?

3. One quart (2 lb.) of boiling water (212° F.) is poured into an iron kettle weighing 6 lb. and having a temperature of 40° F. How much will the water be cooled? Suggestion: Resolve this into four simpler problems as follows:
   (1) How much heat will the water give up if cooled to 40° F.?
   (2) How much heat is required to warm the mixture, consisting of 2 lb. water and 6 lb. iron, 1 degree Fahrenheit?
   (3) How many degrees will this mixture be warmed by the available heat from the hot water?
   (4) What final temperature will this change in temperature give?

4. An egg, weighing 260 gm. and having a specific heat of 0.8, is taken from the refrigerator at 12° C. and dropped immediately into 100 gm. of water at the boiling temperature (100° C.). To what temperature will the water be cooled?

5. Which is the best bed warmer, a hot-water bottle containing 1 qt. (2 lb.) of water at 200° F., a 7-lb. flatiron at 200° F., or a brick weighing 5 lb. heated to 200° F.?

Heat of combustion. We burn fuels to get heat. During all combustion, heat is liberated. In a somewhat similar way, foods give off heat when oxidized in the body, but the temperature of this oxidation is much lower than the temperature of ordinary combustion of fuels. The *heat of combustion* of any substance is the quantity of heat energy given off in the combustion of a unit of weight, 1 gram or 1 pound, and is expressed in calories or B.t.u.

The amount of heat given out during the combustion of coal or of a piece of bread can readily be determined with an apparatus known as the **bomb calorimeter**, Fig. 65. This has an inner chamber where the food or fuel can be placed with compressed oxygen and then set on fire

by means of an electric current. This chamber is surrounded by water which absorbs the heat given up during combustion. From the weight of water and its rise in temperature, it is a simple matter to find how much heat resulted from combustion. It is by this method that the fuel values of various foods and fuels are determined.

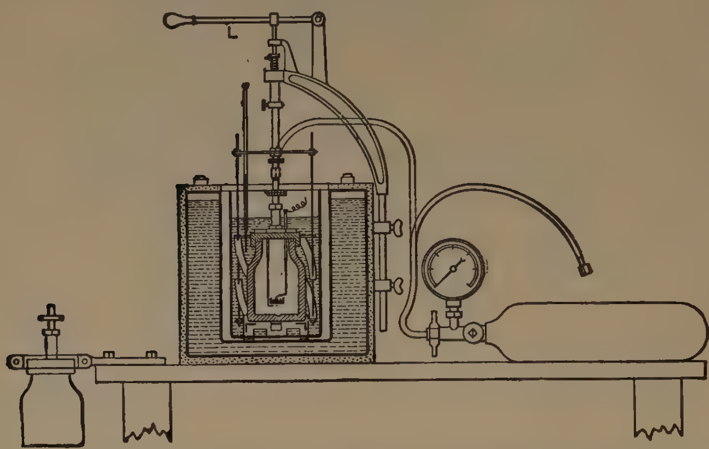


FIG. 65.—Bomb calorimeter. Oxygen for combustion is supplied from the tank at the right.

Conversion of heat of combustion from metric to English units is made by multiplying calories per gram by 1.8. The product is B.t.u. per pound. The heats of combustion of a few combustible materials are compared in the following table:

TABLE V

HEATS OF COMBUSTION

(calories per gram)

Ethyl alcohol	7180	Coke	7000
Denatured alcohol	6450	Coal gas	6000–11,000
Methyl alcohol	5300	Hydrogen	34,000
Anthracite coal	7600–8400	Fuel oil	10,300
Bituminous coal	6100–7800	Gasoline	11,400
Wood	4500–5200	Kerosene	11,100

Specific heat in everyday life. If equal quantities of heat are given to equal weights of water and of earth, the earth, because of its lower specific heat, will be warmed to a higher temperature, Fig. 66. For this reason, the land gets warmer than the water of the ocean or lake when under the direct rays of the sun. This is important in modifying climate, as it causes winds to blow from the cooler water in hot weather,

and the water gives out much of its stored heat in cold weather, thus moderating the climate of nearby land.

You will readily understand that substances with high specific heat can store up more heat during a given change in temperature than can substances of low specific heat. Milk, tomatoes, and oranges will cause more ice to melt in the refrigerator than equal weights of cheese, butter, and meat, for the reason that milk, tomatoes, and oranges have higher specific heats than cheese, butter, and meat. Other important applications of specific heat are found in building materials, house heating, fireless cookers, and many other items commonly found in the home.

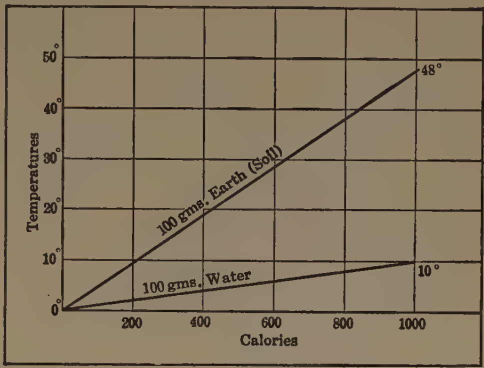


Fig. 66. — The same amount of heat that warms 100 grams of water 10° will warm 100 grams of earth nearly 50°.

QUESTIONS

1. Bread and the pan in which it is baked are at the same temperature when taken from the oven, yet you might get a severe burn by touching the metal pan, while no harm would result from touching the bread. Why is this so?

2. The walls of the oven and the air in it are the same temperature. Some people test the temperature of the oven by holding the hand in it for a moment, but if they touch the wall of the oven they are badly burned. Explain.

3. Discuss this statement: "There is no such thing as a cold body."

4. Why do two people often disagree on whether a given room is warm or cold?

5. State as many reasons as possible why water is such a universal fire extinguisher.

SUMMARY

1. Temperature is the degree of heat in a body.
2. Cold is the absence of heat.
3. One important effect of heat is that it causes a rise in temperature.
4. The sense of feeling is unreliable as a means of judging temperatures.
5. Thermometers are instruments for indicating temperatures.
6. Temperature is not the same as heat.
7. Temperature is one of three factors essential in determining the quantity of heat.

8. A British thermal unit (B.t.u.) is the quantity of heat required to warm 1 pound of water 1 degree Fahrenheit.

9. A calorie is the quantity of heat required to warm 1 gram of water 1 degree Centigrade.

10. When a substance cools through any number of degrees, it liberates the same quantity of heat that would be required to warm it to its original temperature again.

11. Different substances have different heat capacities.

12. Specific heat is the quantity of heat required to warm a unit weight of a substance 1 degree.

13. Water, the standard substance for heat measurements, has a specific heat of 1.

14. Three essential factors in calculating the quantity of heat a body gains in being warmed, or which it loses in being cooled, are: weight, change in temperature, and specific heat.

$$\text{Heat} = \text{weight} \times \text{change in temperature} \times \text{specific heat.}$$

15. Specific heat may be determined by the method of mixtures or by means of the ice calorimeter.

16. The bomb calorimeter is used in finding the heat of combustion of fuel and foods.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Buying coal by the calorie.
2. The nutrition calorimeter and its value.
3. Test two flatirons for heat capacities.
4. Find the specific heat of butter by the ice calorimeter.

CHAPTER VI

HOW HEAT TRAVELS

Movement of heat. A pudding just out of the oven is set into a pan of cold water to cool it quickly. If a thermometer is placed in the pudding and another in the water, it will be observed that as the pudding grows colder the water becomes warmer. A cold flatiron is placed on the hot stove, and in a short time the flatiron is hot. A hot-water bottle warms the bed clothing near it. When removing a skillet of boiling water from the gas flame, you find that the metal handle, which was not near the flame, is too hot for you to hold in the bare hand.

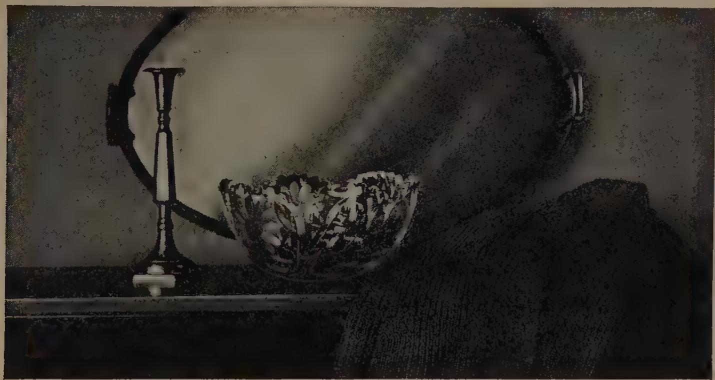


FIG. 67. — These objects may have the same temperature and yet some of them feel colder than others. Why?

The water in the skillet has been warmed to the boiling point, though separated from the flame by the metal. From this evidence you reason that the heat derived from the gas has traveled through the metal and entered the water; also that the heat has traveled from the heated part of the metal to the cold part; and that when you touch the handle, which is hotter than the hand, heat travels into your hand.

These examples illustrate an important property of heat, namely, that *when any two bodies having different temperatures are in contact, heat passes from the body of high temperature to the one of low temperature,* and that in a single substance heat moves from points of high temperature to points of low temperature. This kind of heat travel is called **conduction.**

Conduction explained. The scientist explains the conduction of heat as follows: All bodies of matter are made up of very small particles or molecules, which are always in vibration. The addition of heat to a body makes the molecules vibrate more rapidly. It is therefore believed that the molecules in a hot body are vibrating more rapidly than they are in the same body when its temperature is lower. The adjacent molecules, though not in permanent contact with each

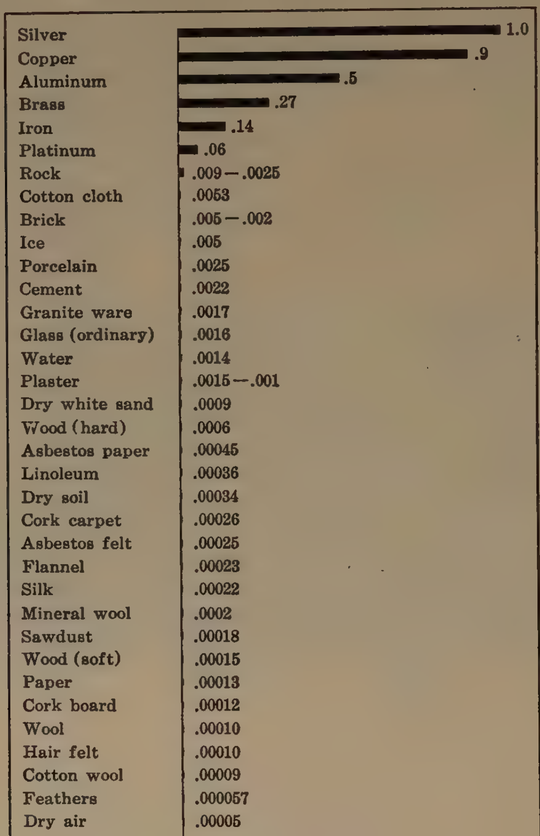


Fig. 68. — Relative thickness to give equal heat insulation.

other, do come together and strike frequent blows upon each other. Molecules having greater energy will give up some of this energy to those with less, and these in turn carry it on to still other molecules, so that in time molecules far removed from the source of heat will receive some of the transmitted energy by this process of conduction.

Since heat flows from places of high temperature to those of low temperature, objects which have been in contact with the air of the

room for a time will all have the same temperature. They do not all "feel" the same temperature, as was explained in Chapter V. Suppose that the air is at a temperature of 70°, and we touch a brass candlestick, a glass dish, and a woolen sweater. If we judge by the sense of feeling alone, we say that the brass is cooler than the glass or wool, and the wool is warmer than the brass or the glass. Since in reality they are

TABLE VI

THERMAL CONDUCTIVITY

(In calories per second per square centimeter per degree Centigrade per centimeter thickness)

Vacuum-silver jacket 0.001 mm. pressure	0.000002
Air (no convection)	0.000060
Calorox (fluffy mineral matter)	0.000076
Kapok (loose vegetable fiber)	0.000082
Pure wool (6.9 lb. per cu. ft.)	0.000084
Pure wool (5 lb. per cu. ft.)	0.000090
Pure wool (25 lb. per cu. ft.)	0.000101
Hair felt	0.000085
Mineral wool (loosely packed)	0.000090
Cotton wool (loosely packed)	0.000100
Cork board (low density)	0.000096
Cork board (high density)	0.000106
Celite (infusorial earth)	0.000106
Wool felt	0.000125
Wall board	0.000150
Asbestos paper	0.000170
Insulex (asbestos and plaster)	0.000194
Fire felt (asbestos and cement)	0.00021
Cypress (across grain)	0.00023
Asphalt roofing (felt and asphalt)	0.00024
White pine (across grain)	0.00027
Oak (across grain)	0.00035
Hard maple (across grain)	0.00038
Gypsum plaster	0.00078
Asbestos wood (asbestos-cement)	0.00093

all at 70°, how is it that we are deceived? A simple test will make it possible to answer this question.

Hold an 8-inch brass rod in one hand and an 8-inch glass rod in the other. Let the free ends of these rods extend into a gas flame. Which one brings the heat to the hand first? Is this substance a better conductor of heat? If a wooden rod is used, will it bring heat as well as the metal? If the metal rod brings heat to you faster than the glass or the wood does, what would you expect when you touch rods of iron, of glass, and of wood, which are all at the same temperature and all colder than the hand? Which one will take heat from the hand most rapidly?

It must be evident to you now that, if you place your hand upon different objects having the same temperature and colder than the hand, heat will be conducted away from the hand by all of them; but since metals are better conductors of heat than glass they will remove more heat in a given time, and therefore the hand will feel cooler. Likewise, since glass conducts heat better than wool, it will feel colder than the wool.

Fat is a poor conductor of heat. The longer time needed for roasting a large piece of meat is due largely to this fact. Much food is preserved by the cold pack. Glass, water, and the food are all poor conductors: hence much time is needed to bring the food in the center of the jar to the required temperature. Some cake tins have a central tube. The hot metal brings heat to the center of the cake and reduces the time required for baking.

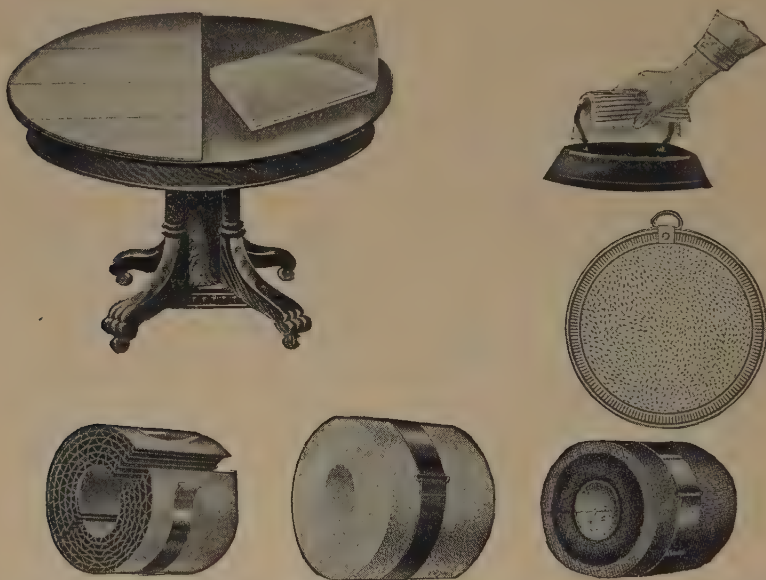


FIG. 69. — Household uses of asbestos. Table cover, flatiron holder, stove mat, and three pipe coverings in order of pictures, air cell, 85 per cent magnesia, and hair and wool felt.

Advantages of good conductors and of poor conductors. Have you ever used an aluminum saucepan with an aluminum handle, with an iron handle, and with a wood-covered handle? If you have, you can appreciate the disadvantage of the aluminum handle, the improvement made by the use of the iron handle, and the still greater advantage of wood. Aluminum conducts heat four times as well as

iron and one thousand times as well as wood. An aluminum kettle transmits the heat to the contents around the sides almost as well as on the bottom, but an iron kettle transmits comparatively little heat around the sides. Aluminum has the advantage of giving the heat more quickly, and of distributing it more evenly to the material within it. It is, therefore, an ideal material for many types of cookers.

Heat insulators. Some substances are such poor conductors of heat that they may be called *heat insulators.* This property is utilized in two ways: to keep heat away, and to hold the heat in. We pack ground cork and used layers of felt in the walls of a refrigerator to keep heat

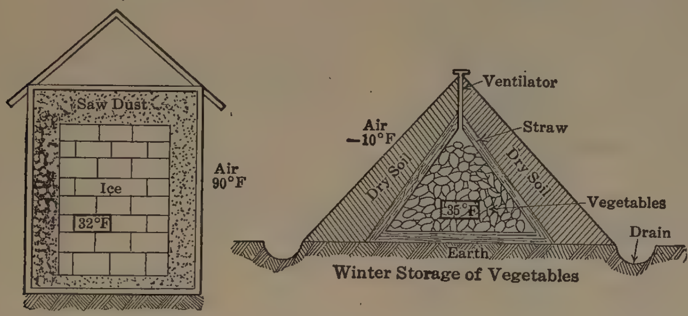


FIG. 70.—Preserving ice and vegetables by means of heat insulators.

out, and mineral wool or magnesia in a fireless cooker to keep the heat in. We lay pads on the table under hot dishes to keep the heat from reaching the table, and we put a wool jacket around the coffee pot to prevent its losing heat. But whether it is to save the heat or to protect something from the effect of heat, the poor conductor is an efficient and effective agent. As a rule, we desire to prevent loss of heat from steam pipes. This is done by surrounding the pipes with a heat insulator, such as magnesia or asbestos.

It has been estimated that in home heating systems 25 per cent of the fuel used is now lost. This is an average waste of two tons of coal a year per family. If pipes and furnaces were covered with asbestos, this loss could be reduced to one-half ton.

In the storage of ice, the ice is surrounded by dry sawdust. The thicker the layer of sawdust the less heat will penetrate it to melt the ice. Storage of vegetables through the winter is possible by utilizing the protection of dry soil. A central pit holds the vegetables. These are covered first with a layer of straw and then with a thick layer of earth as indicated in Fig. 70. There must be good drainage to keep the vegetables and soil dry. Moist or wet vegetables will mold or rot.

Dry air is a poor conductor of heat. The value of double windows and storm doors is due to the poor conduction of heat by the enclosed air. The warmth of fur, wool, and other clothing is largely due to air held in the spaces between the fibers. Air spaces between the roof of a house and the ceiling, and air spaces within the walls, prevent the penetration of the extreme heat on a hot summer day. Heat insulators are of great importance in ice storage.

Fig. 71.—Firefighter, clothed in asbestos.

QUESTIONS

1. Why does sawdust give better protection against heat than the solid wood from which the sawdust comes?
2. Asbestos is a better conductor of heat than air. Why then, in order to save heat, do we wrap steam pipes in asbestos rather than allow them to be surrounded by the air of the room?

Convection currents. In Chapter IV we saw how heat produces a difference in density in liquids and gases, and how under the force of gravity this results in the actual flow or motion of some of the heated material from one place to another, thus transporting heat from the heat source to places remote from it. These currents, called *convection currents,* are very important in everyday life. In the home we depend upon them very largely in warming the house, in automatically supplying fresh air to the fire, and in promoting ventilation.

Heat from the sun. Day after day, the sun sends out a steady stream of heat, without which there could be no life on the earth. Did you ever stop to think, "How does this heat get here?" We have learned of two ways by which heat can travel, namely, *conduction* and *convection.* These modes of travel require the assistance of matter, and there is no matter connecting the earth and the sun. The air of the earth extends, at the most, only a few hundred miles, while the heat energy from the sun must traverse a space of 93,000,000 miles to reach us.

Evidently there must be some ways for heat to travel entirely independent of matter. Many scientists believe that all space is filled with an invisible, weightless medium quite unlike matter, called **ether,** which is able to transmit heat energy for any distance without loss.

Radiation. Energy, radiated from the sun, travels as ether waves. Light, as well as heat, travels in the ether. Electrical energy borne by the ether carries the radio broadcasts and wireless messages. Ether waves vary in length and frequency of vibration. The longest waves are the electrical waves used in radio. Heat waves are shorter than the radio waves, but longer than those which produce light. All these waves are forms of radiant energy. The transmission of energy by means of ether waves is called *radiation.* Since ether is present everywhere, even between particles of matter, energy may be radiated through matter. The heat we feel when we stand before a fire in a fireplace does not reach us by conduction, because air is the poorest of all conductors; neither does it come by convection. It does come to us by radiation. The molecules of matter interfere to a slight degree with the passage of radiant energy, and yet the speed of ether waves through some forms of matter is nearly as great as it is in space containing no matter.

Relation of ether waves to molecular motion. When heat and light ether waves are absorbed by matter, they increase the molecular vibration and so raise the temperature. Molecular vibration in an object will set up ether waves, and when this happens, energy is lost by the body. Every object, then, may be considered as radiating heat and also as receiving radiant heat from other bodies. At high temperatures, ether waves of shorter length are produced, and light results.

Absorption of radiant energy. In order to compare the relative ability of black and white surfaces to absorb radiant energy, we may fill two test tubes nearly full of water. Have equal amounts of water in the two tubes. Wrap one with one thickness of black paper and the other with one thickness of white paper. Put thermometers into the two tubes, and note at the start that the water is at the same temperature in both tubes. Place the tubes where they will receive direct sunlight. A radiant gas heater or electric heater placed 2 feet away from the tubes may be substituted for the sunlight. Read the thermometers at two- or three-minute intervals. It is soon seen that the temperature in the black-covered tube is rising much faster than that in the white-covered tube. It is a demonstrated fact that dull, black, rough surfaces absorb radiant heat better than smooth, white, polished surfaces. In a similar way, when the sun shines upon a black cloth and a white cloth, both covering snow, it is found that more snow melts under the black cloth than under the white

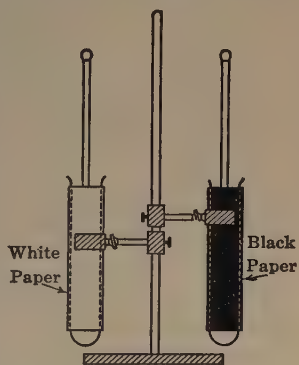


Fig. 72. — Absorption of radiant energy by black and by white bodies.

one. The black absorbs, while the white reflects, the greater part of the radiant energy.

Radiation. Why is the bottom of the teakettle dull and rough, and the inside surface dull and rough, while the exposed outside surface is bright and smooth? Let us pour equal quantities of hot water into two metal cans, one of which has a dull, black, rough surface, and the other a bright, white, smooth surface, Fig. 73. The temperature of the

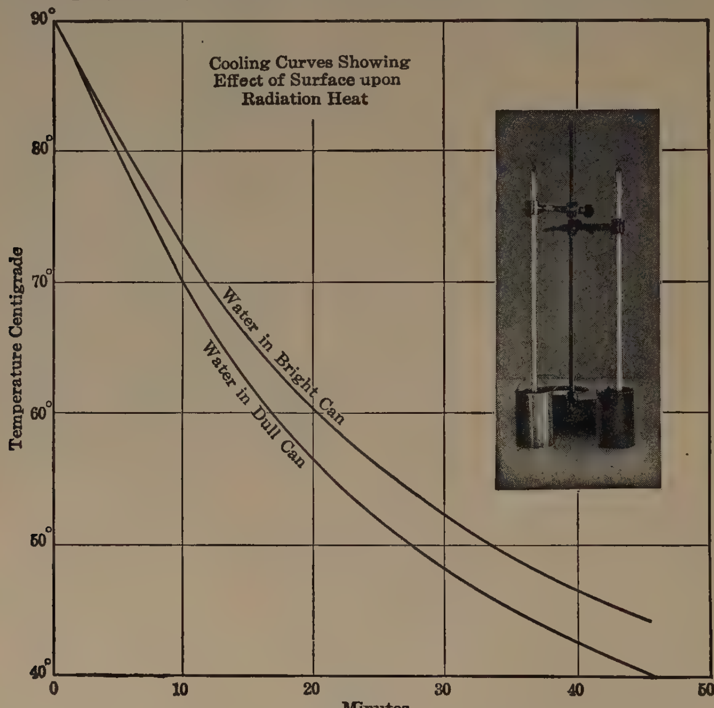


Fig. 73.—Curve showing that the dull black can radiates heat faster than the smooth white can does.

water in the two cans at the start is the same. If we observe the thermometer in each can at ten-minute intervals, it will be seen that the water in the black, rough can is cooling faster than that in the bright, smooth one. This is due to the fact that one is radiating heat faster than the other. A smooth, bright surface helps to retain the heat. A time-temperature curve for each of the cans is shown in Fig. 73. We wish our steam and hot-water radiators to give off heat rapidly and not to retain the heat. For this reason our radiators are dull and rough.

The vacuum bottle. Whether an object is being heated or cooled, all three methods of heat movement are usually involved. A hot iron

conducts heat to the air in contact with it. This heated air is removed, and other cold air brought into contact with the iron, by convection. The iron also *radiates* heat in all directions.

Fig. 74. — Take-down view of a vacuum bottle. The parts shown are metal cap or drinking cup, metal shoulder with leak-proof gaskets, metal case, cork stopper, and double-walled glass filler standing in a shock absorber.

It is desirable at times to prevent the loss of heat from foods and drinks, or the access of heat to them. The vacuum bottle, Fig. 74, and

Fig. 75. — Non-breakable enameled steel bottle.

the vacuum fruit jar are very efficient devices for accomplishing this. A double glass bottle, really one bottle within another, connected only at

the mouth, holds the liquid to be kept hot or cold. Air is removed from the space between these two bottles, to prevent conduction across the space. The walls of the vacuum space are silvered, and are thus made to reflect radiant energy like a mirror. Heat radiated from the inner bottle across the vacuum is largely reflected back by the silver mirror on the outside of the vacuum. The glass itself is a poor conductor and is separated from the outside metal container by an air space. It is thus made so difficult for heat to travel in either direction across the space that hot liquids keep hot and cold liquids keep cold for many hours. A wide-mouth container, for holding foods other than liquids, is made on the same plan. In place of glass, a double-walled enameled steel bottle may be used. This is very efficient and is in less danger of breaking.

Clothing. Besides the shelter of buildings, civilized man uses clothing for protection against the cold. If one wears summer-weight clothing in winter, one's body loses an excessive amount of heat, and this loss of body heat must be made up by consuming more food. The value of clothing as a heat insulator comes partly from the poor conducting property of the fiber itself and partly from the presence of air enclosed by the fibers. Wool fibers, because of their saw-tooth edges, when matted together, form many minute spaces for holding air; cotton and silk, whose fibers have smooth surfaces, do not hold air as well. Fur and feathers protect animals against the cold largely because of the air enclosed and held stagnant. In hot weather the clothing should assist the body to lose heat. It should be a good conductor, as cotton and linen, porous to permit circulating air to reach the skin, and absorptive to take up moisture resulting from perspiration. Evaporation of moisture is a process which absorbs heat and is frequently a means of keeping one comfortably cool.

House construction. Most of the time it is desirable to have the walls of the house check the passage of heat through them, in cool weather to keep the heat in, and in hot weather to keep the heat out. The heat-insulating property of air, paper, wood, and other materials is utilized in buildings. The wall of the ordinary wooden house has, in its cross section, clapboards, sheathing paper, boards, air, laths, plaster, and wallpaper. These are all poor conductors. Many concrete and stucco houses have hollow tile walls to hold the surface coating. Air is held in small spaces in the tile, and large convection currents, such as take place in the walls of wooden buildings, cannot be produced. Rooms directly under flat roofs are very hot under the direct rays of the summer sun. The pitched roof, having an attic space which holds air, is much cooler. Thick walls with small air spaces keep the heat in

or out better than thin walls or solid walls. The loss of heat through the walls depends upon the outside and inside temperatures. The chart of Fig. 76 shows the loss of heat through walls under moderate exposure

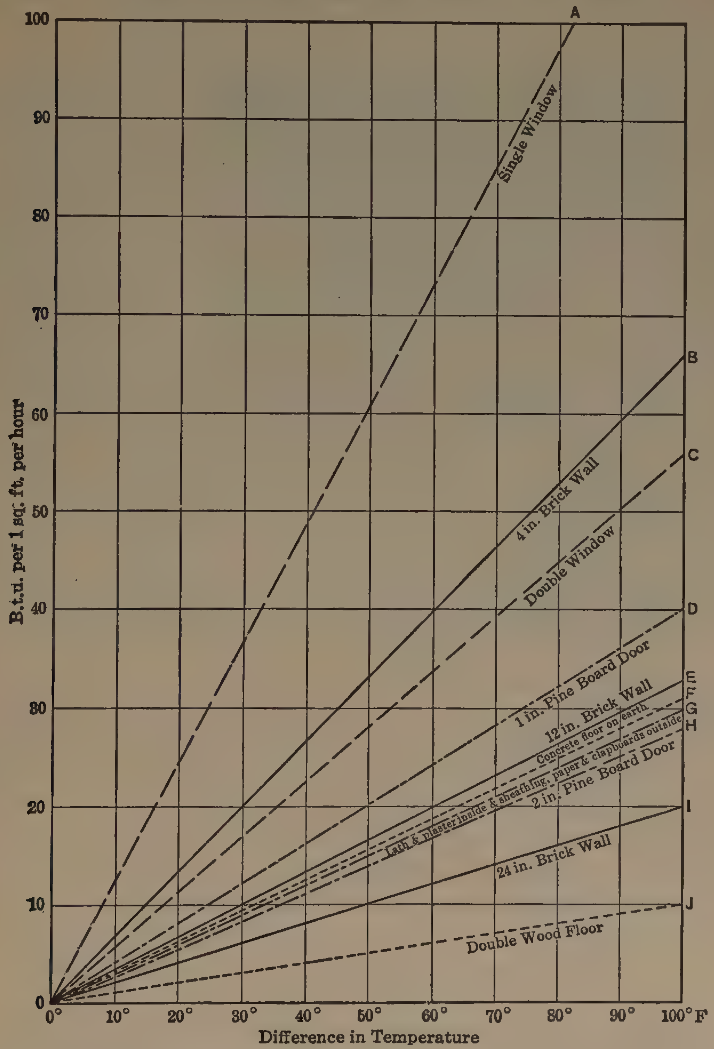


Fig. 76. — Heat losses through building materials under moderate exposure to wind.

to wind. The losses will be greater on northern and western exposures, because our cold winds are those from the north and west. You will also see from the chart that, if the difference between indoor and outdoor temperatures is doubled, the heat loss is doubled, or that the rate

of heat loss through windows, doors, and walls is directly proportional to the difference between inside and outside temperatures.

House insulation. When new houses are constructed, much attention should be given to providing insulation. Mineral wool or similar preparations which are insulators themselves and also provide many

FIG. 77. — Insulating a house with rock wool.

minute air spaces are packed loosely within the outside walls and under the roof. These materials are fireproof, act as fire stops, and effectively retard the passage of heat. This insulating material may be blown into the walls of houses already built by making openings in appropriate places. A house properly insulated loses much less heat in winter, and it is cooler in summer as it keeps out the solar radiations.

SUMMARY

1. Heat may be transferred from one place to another in three ways, conduction, convection, and radiation.

2. Heat flows from points of high temperature to points of low temperature by a process called **conduction.** In this process heat energy is passed along from particle to particle in the conducting body.

3. At temperatures below that of the body, good conductors of heat feel colder than poor conductors, because by conducting the heat away

rapidly they maintain a greater difference in temperature between the object and the hand.

4. In **convection** there is an upward movement of the heated portions of liquid or gas, which mingle with the colder portions.

5. Heat is carried by **radiation** by means of ether waves, through some forms of matter and through space where there is no matter. It is by radiation that we receive heat from the sun.

6. Black, dull, and rough surfaces radiate heat better than white, bright, and smooth surfaces. Surfaces that radiate best also absorb heat best.

7. The materials used and the methods of construction of a house are important factors affecting loss of heat in winter or exclusion of heat in summer.

8. The rate of heat loss through the walls of a building is directly proportional to the difference between inside and outside temperatures.

9. Clothing with fibers like those of wool and fur, which enable it to hold much air within its meshes, is warm because heat passes through it with difficulty. In hot weather, evaporation of moisture should be aided by wearing absorbent, porous clothing, such as cotton and linen.

10. House insulation is important in saving fuel in winter and adding cooling comfort in summer.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Which is of more importance to us, heat conduction or heat insulation?
2. Conservation of heat.
3. Test sawdust, sand, loose cotton, paper, etc., for relative heat conductivity.
4. Compare the radiation and absorption by dull, black, rough surfaces with the radiation and absorption by bright, white, smooth surfaces.
5. How is mineral wool or rock wool made?

CHAPTER VII

THE WEATHER

Influence of the weather upon us. Our casual remarks to our friends are oftener about the weather than about any other one thing. We say it is "sharp," "sultry," "sweltering," and, in so doing, we express a physiological effect which the weather has upon us. There is also a psychological effect, which we express when we speak of the weather as being "dull," "close," or "gloomy." Weather conditions are important factors in our homes. We regulate our heating devices according to the weather. The drying of clothes depends on the dryness of the air. An extended period of damp weather favors the molding and decay of foods and other materials. The shrubs, flowers, and vegetables about the house, or in the garden, are chosen with due regard to the climate which results from all the weather factors.

The atmosphere. The atmosphere, as you know, is the entire body of air which surrounds the earth. It is densest at sea level and loses rapidly in density with an increase in altitude. It is believed that the air extends to a height of more than one or two hundred miles above the earth, but more than half of it, by weight, is within four miles of earth's surface.

The air has practically a constant composition except for the moisture content, which may vary from under 1 per cent to more than 3 per cent. Air tends to expand indefinitely and would leave the earth if it were not held here by gravity.

Since air has weight, it exerts pressure. As we ascend a high mountain, the depth of air above is diminished, and the pressure therefore decreases. The chart of Fig. 78 shows how the air pressure varies with the altitude.

The pressure of air is measured by finding how tall a column of mercury it will support. At sea level, the atmosphere will hold a column of mercury about 30 inches high, and exerts a pressure of approximately 15 pounds per square inch. The pressure of the air can be measured accurately by means of an instrument called a **barometer.** Barometer readings are of great value to the Weather Bureau in preparing its weather forecasts.

Substratosphere flight. If we go up into the atmosphere we find that the density of air becomes less, the pressure less, and the air currents stronger but more uniform. The temperature in temperate

latitudes decreases about 3⅓° a thousand feet. At about 35,000 feet, it is —60° F., and remains uniform above this level. This level of uniform temperature is the stratosphere. Just below this, say at about 20,000-foot elevation, is the substratum or the "troposphere," which is

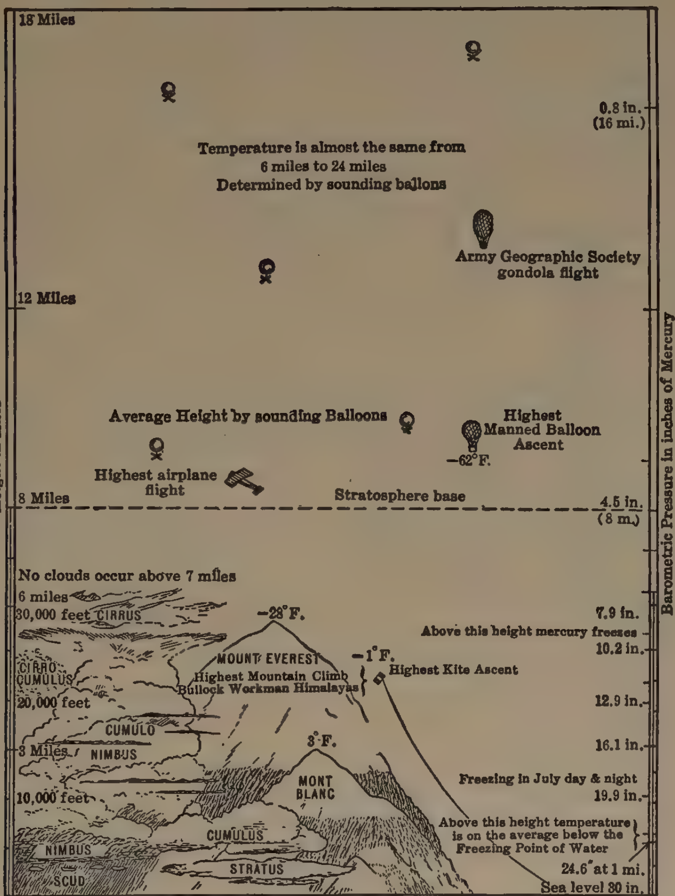


FIG. 78.—Explorations in our atmosphere, clouds, temperatures, and pressures at different elevations.

a layer above most of the clouds and weather disturbances, where the temperature is fairly uniform at —10° F. and the wind much more constant than at lower levels. The air here is not as rare as in the true stratosphere, but rare enough to allow high-speed flight. A 25,000-horsepower plane can make 240 miles per hour here.

We are accustomed to live near sea level with an atmospheric pres-

sure of 15 pounds per square inch. At 10,000 feet the pressure is around 10 pounds per square inch, and most people can endure that in comfort. At 14,000 feet the pressure is around 8.2 pounds per square inch. This affects man unfavorably. Owing to lack of oxygen and to low air pressure, a person becomes sluggish and mentally drowsy. At 18,000 feet the air pressure is reduced to half normal pressure. At 20,000 feet it is 6.7 pounds per square inch. The percentage of oxygen in this low-pressure area is about the same as that at sea level, and so, if the air is compressed, it will satisfy human needs, just as it does at the lower levels. Sealed cabins in airplanes can have surface air conditions inside for passengers' comfort. High-altitude flying removes most of the danger of weather. The weather hazard would be present only when leaving port for higher altitude, and when descending at the destination.

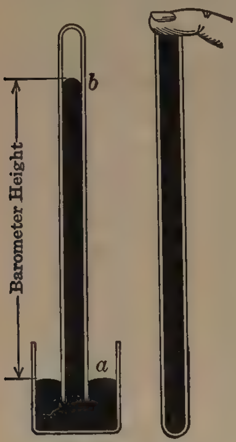


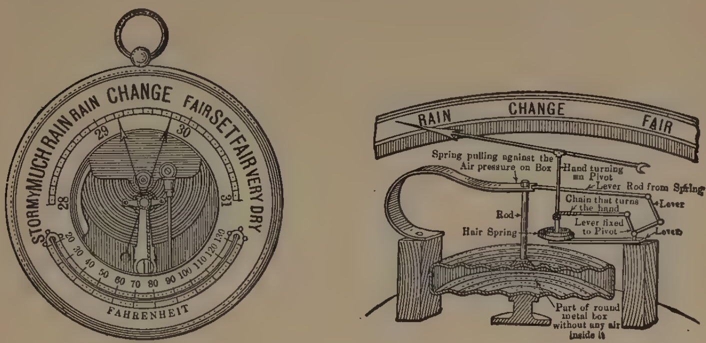
Fig. 79.—Principle of mecurial barometer.

Weather factors. Weather is the condition resulting from many factors in our atmosphere. Heat, cold, moisture, dryness, sunshine, cloudiness, pressure, winds, and electrical disturbances are the important variable factors of the atmosphere which determine our weather. Other fixed factors affecting weather are: land and water areas, mountains and valleys, ocean currents, and the changing seasons which bring variation in solar radiations received.

Experimental barometer. Fill a glass tube, about 35 inches long and closed at one end, nearly full of mercury. Cover the open end of the tube with the finger. Invert the tube, and allow the large bubble of air to pass through the mercury to the opposite end of the tube. Slowly invert the tube again and let the air come back, gathering with it all the small air bubbles that were enclosed with the mercury. Fill the tube full of mercury. Close the open end with the finger, being careful that no air is left under the finger, invert the tube, place the end under the surface of mercury in a small vessel, and remove the finger. When the tube is vertical, as in Fig. 79, the mercury will fall until its downward pressure is just balanced by the pressure of a column of air on the surface of the mercury in the vessel. When all the air is removed from the mercury in a barometer tube by heating to a high temperature, very accurate measurements of air pressure can be made. There is always a vacuum in the tube at the top of the mercury column. A scale running from 28 inches to 32 inches above the mercury level in

the reservoir makes it possible to observe the variations in the pressure of the atmosphere from day to day. At any given place the pressure of the atmosphere may vary by about 3 centimeters or a little more than 1 inch of mercury. The standard pressure, which is the average at sea level, is 29.92 inches or 76 centimeters. This is equivalent to a pressure of 14.7 pounds on every square inch of surface in contact with the air.

When a 32-inch tube stands in a vessel of mercury and the open top end is connected by a pressure tubing to a powerful exhaust air pump in action, mercury rises in the tube to the same height as in the barometer. This same principle is used when you " suck " soda through a straw. The pressure inside the tube is reduced, and outside atmosphere pushes the liquid up into the tube.



(a) (b)

Fig. 80.—Aneroid barometer. Section of the same showing how motion of the side of the box causes pointer to move over dial.

The aneroid barometer. The mercurial barometer is the standard weather instrument; but for many purposes, as in making a continuous record of the atmospheric pressure, in measuring heights of mountains, in getting data for contour maps, and in registering the elevation of an airplane, a lighter and more compact instrument, such as the aneroid barometer, Fig. 80, is better. The aneroid barometer accomplishes the same purpose as the mercurial barometer, but it works on a somewhat different principle. The essential part is a thin metal box, with corrugated sides, from which the air has been partly removed. This leaves less air pressure inside than outside the box and, as a result, the sides are forced inward. An increase in atmospheric pressure causes them to move still further inward, but upon a decrease in pressure the sides spring out. The actual amount of movement of the sides of the box is

very slight, but by means of a series of levers the indicating pointer moves over a relatively larger space on the scale which indicates the pressure. The scale must be graduated by comparison with a mercurial barometer.

The sun as a factor in weather. Wind, temperature, and moisture in all its forms are under the control of the sun. Whether we have skating or boating, skiing or baseball, in our northern states, depends upon the duration and intensity of sunshine. The sun's heat is greater under the direct or more perpendicular rays of the sun, which, for our latitude, are received when the sun is farthest north of the equator and the days longest. When days are short and nights are long, the earth loses more heat than it receives, and winter's snow and ice cover the earth. During the period of long days and short nights, more heat from the sun is absorbed by the earth than is given off, and so the earth is warmed and crops grow.

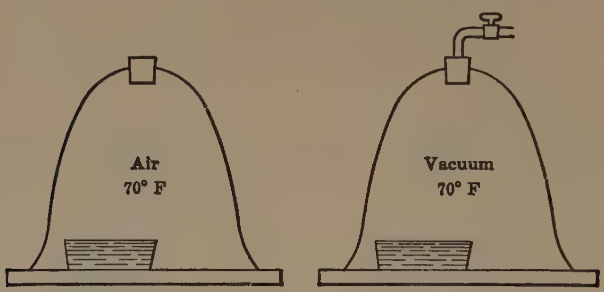


FIG. 81. — Under equal conditions of volume and temperature, equal amounts of water vaporize to fill the space regardless of presence or absence of air.

Clouds interfere with radiation. They prevent much radiation of energy from reaching the earth from the sun, and they also prevent the earth from losing heat by radiation.

Heat is a most important agent of weather. Heat is the one agent, above all others, which determines weather. Heat is involved directly in the temperature of the air. It also affects weather indirectly, by determining dryness, moisture, rain, wind, lightning, and frost. Since heat is directly responsible for the moisture of the air, it follows that it must be an important factor in the production of fogs, clouds, and precipitation.

Moisture in the air. We commonly speak of the air holding moisture, just as if the air could take up moisture and hold it in a sort of solution. This conception is easy to understand, but it is not scientifically correct. In fact, the amount of water vapor which will enter an enclosed space

above the surface of water, at a given temperature, will always be the same, irrespective of the presence or absence of air in that space. See Fig. 81. The important thing that determines the amount of water vapor which will saturate a given space is the *temperature.* The amount of water vapor in a given space depends also upon pressure, but as the usual variation in pressure of the air is small, the effect of pressure is of little consequence.

Saturated air. Bodies of water, swamps, and forests are constantly losing water, which, in the vapor state, enters the surrounding air or space. There is, to some extent, a reverse action at the surface of the water, where moisture is passing back from the gaseous state to the liquid. When so much water vapor is present that no more can enter the air without an equal condensation, the **saturation point** has been reached. Table VII shows the weight of water which will saturate 1 unit volume of space or air at different temperatures.

TABLE VII

WEIGHT OF WATER VAPOR REQUIRED FOR SATURATION AT DIFFERENT TEMPERATURES

English				Metric	
Temperature Fahrenheit	Grains of Water Vapor per Cubic Foot	Temperature Fahrenheit	Grains of Water Vapor per Cubic Foot	Temperature Centigrade	Grams per Cubic Meter
—20°	0.21	65°	6.79	—20°	1.08
0°	0.32	70°	7.98	—10°	2.36
10°	0.78	75°	9.36	0°	4.84
20°	1.23	80°	10.93	5°	6.77
30°	1.94	85°	12.74	10°	9.33
40°	2.85	90°	14.79	15°	12.73
45°	3.42	95°	17.13	20°	17.12
50°	4.07	100°	19.76	25°	22.82
55°	4.85	104°	22.12	30°	30.04
60°	5.74	...	.....	35°	39.23

Saturated air at any temperature, if warmed, becomes unsaturated and able to take up more moisture. Saturated air, when cooled, remains saturated, but loses a part of its moisture by its condensing into liquid. The temperature at which cooling air becomes saturated is called the **dew point.**

Humidity. The actual amount of water vapor in a unit volume of air is the **absolute humidity.** The ratio of the absolute humidity to the amount of water vapor required to saturate a unit volume of air at a

given temperature is the **relative humidity.** Saturated air always has a relative humidity of 100 per cent, meaning that the air is 100 per cent saturated. Air which is saturated at 50° F., if warmed to 85° F., would be approximately four-twelfths or one-third saturated, and would have a relative humidity of 33 per cent.

Causes of condensation. Moisture in air is condensed when any cooling process lowers its temperature below its dew point. The cooling may be caused by: (1) mixing with cooler air; (2) radiating heat to cooler bodies near by, as to the cold ground, bodies of water, and ice; (3) contact with colder bodies, as grass and stones, which receive a deposit of dew or frost; (4) expansion — rising air expands, and by this process is cooled 1 degree for every 180 feet.

Dew and frost. As the earth radiates heat after the sun has set, grass blades and twigs, which are exposed to the air more than the earth itself, radiate heat faster, and become cooled to a lower temperature than the earth. Because of this, two hours after sunset the gravel walk may be 10 degrees warmer than the grass lawn beside it. If the air in contact with the grass is cooled until its relative humidity rises to 100, further cooling will result in condensation. The grass blades and plants receive a deposit of dew sooner than rocks and sand, because they become cold sooner, and cause the air close to them to reach the dew point before the air in contact with rocks and sand does. If the temperature is below 32° F., a frost results instead of dew. For reasons given above, there may be frost on the grass when there is none on the bare earth or on the gravel or cement walk.

When the air is still and there are no clouds, heat is radiated best. Thus it is that we have the heaviest dews or frost on still, cloudless nights. Since cold air is denser than warm air, it tends to flow into the valleys and upon the low land, lifting the warmer air, which may envelop the hills. For this reason we frequently hear of a frost on low land, on a night when there is no frost on high land near by. Another reason for frost on low lands is found in the fact that frequently the low land is much wetter than the high land. The wet land will not get so warm during the day and will be colder at night.

Clouds prevent frost by preventing the loss of heat from the earth by radiation. Winds prevent frost by diffusing warm and cold air, preventing the separation of air into layers of different temperatures. Plants and garden truck are saved from frost by covering with papers, cloths, or boxes, as this covering prevents the radiation of heat. Blossoms and fruit in apple orchards and orange groves are saved, in the West and South, by placing small pots of burning oil at short distances apart, throughout the groves. The smoke and moisture rising from the

fires sometimes form a blanket over the grove, but direct radiation from the fires is depended upon, chiefly, to keep the temperature above freezing.

Fogs. A *fog* is in reality a cloud at the surface of the earth. When a fog is increasing in density the air is saturated and condensation is taking place. A person's clothes will become damp at such a time. This is called a **wet fog** and is likely to occur with a falling temperature. At other times a person may go into a fog without receiving any condensed moisture on his clothing. This is because the air during a rising temperature is unsaturated and the particles of moisture are being taken up by the air. This is called a **dry fog.** If the process continues long the fog will disappear. Low clouds often disappear before one's eyes by a similar process.

Clouds and rain. Millions of tiny particles of water, either in liquid or in solid form, are produced by the condensation resulting from cooling

Fig. 82. — Water crystallized in snowflakes.

below the dew point. If the temperature is below freezing, ice particles will result, taking beautiful crystal shapes, shown by snowflakes, Fig. 82. If the temperature is above freezing, the condensed particles will be liquid. A cloud consists of a multitude of these particles floating high in the air. Condensed moisture is heavier than air, and yet very tiny particles are buoyed up for a long time. There is, however, a gradual settling of these particles. As they settle, they may enter warmer, unsaturated air, and there evaporate. If two particles touch each other, they may coalesce and form larger droplets. The particles may also be increased in size by continued condensation in saturated air. The larger the droplets become, the less their surface in proportion to their weight, and as a result they are less easily held up by the air. In time they become so large that they fall as rain or snow.

Winds. Air over land or water warmer than the air absorbs heat and becomes warmer. Air over land or water cooler than the air itself loses heat to the cooler body and is cooled. Because of its lower specific heat, land is heated to a higher temperature than water under the same radiant energy from the sun, and for the same reason it cools more rapidly. The land near the coast of a large lake or the ocean becomes hotter than the adjacent water during the day, and the colder air from the water moves in under the warmer air producing convection currents. This movement of air from water to land is the refreshing *sea breeze* people at the seashore enjoy on a hot day. As soon as the sun sets, the land loses heat faster than the water, and if the land becomes cooler

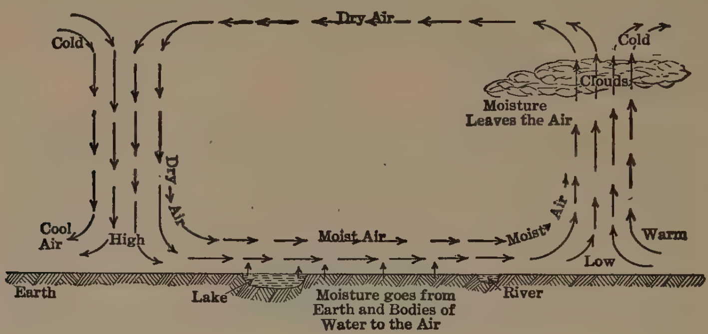


FIG. 83.—Circulation of air in "high" and "low" areas. Natural convection currents on a large scale produce many of our winds.

than the water reverse convection currents are produced and a land breeze results. The sea breeze generally continues until after sunset and the land breeze until after sunrise. There is a short period of calm between the two. A seasonal change based upon the same fundamental principles results in the monsoons which are particularly well developed in the south and in southeast Asia. In summer, the winds blow from the ocean to the land carrying much moisture. In winter, they blow from land to water. These winds are rather steady for a period of three to four months. In spring and autumn comes a period of uncertain calm or shifting winds.

The vertical rays of the sun never entirely leave the torrid zone. The heat equator varies with the season, moving south of the equator over the continents during our winter. Rising currents of air along this belt are caused by an inrush of air from both north and south; they result in a belt of *equatorial calms* or *doldrums*, a region of heavy rainfall and sultry climate.

The winds that blow over the oceans toward the heat equator are

called *trade* winds. Because of their constancy they have been used extensively by sailing ships in carrying on trade. These winds are deflected by the rotation of the earth from their north and south directions. Those blowing from northeast to southwest are the *northeast trades;* those blowing from southeast to northwest are the *southeast trades.* When blowing from sea to land they are moist and yield much rain, but when they blow over the land they are dry and produce desert conditions such as are found in Arabia and the Sahara. In the temperate zones, although there is a great variety of wind direction, the prevailing winds are from the west. These *prevailing westerlies* determine the direction of our cyclonic storms and cause them to move from west to east across the United States.

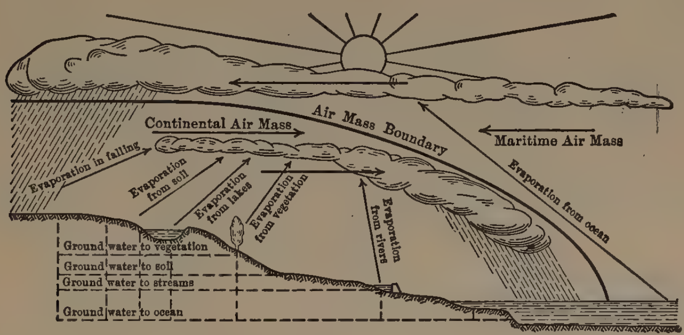


FIG. 84. — The water cycle.

Air mass movements. There is much variation between the tropics and polar regions. Owing to the unequal amounts of heat received by the air at different latitudes large masses of air are set into motion. A large temperature difference is the driving force in all large-scale air movements. Polar air moves toward the equator, and equatorial air toward the poles. A horizontal difference and large masses moving result in slow sinking and slow rising on a still earth. Many factors complicate this movement so that it is seldom directly in a north and south line. Currents are deflected, and we may get surface currents in both directions. Movements are more intense in winter than in summer. An air mass that comes from the artic region and passes over a continent can have relatively little moisture in it. An air mass that comes from either tropical ocean or the Gulf of Mexico has a large amount of moisture in it. Polar currents over the Great Lakes give heavy rain or snow. Tropical currents may give low clouds, drizzles, not much rain, and no upward currents. Because of the greater density

of the polar currents they will as a rule slide in under the tropical currents. Sometimes, however, two large air masses may move close to the surface in opposite directions. Warm and cold air coming in contact make a vortex and produce a large storm. The center of the vortex is a low barometric area. Continental air does not pick up enough moisture to account for all the rain received by the continents. It is believed that most of the moisture taken from the continent by the air is carried off and precipitated over the ocean. The heavy rains on the continent come chiefly from moisture taken from the oceans by the maritime air masses.

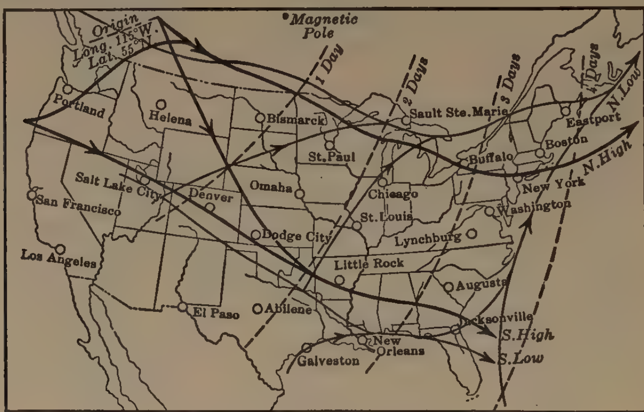


Fig. 85. — Storm tracks across the United States.

For reasons not yet understood, upper air which has lost its moisture and is dry and hot sometimes settles to the surface. In July, 1936, this dry air produced the drought condition over the Great Plains. Cloudless skies and extreme heat parch the earth and give no rain.

Storms. Storms may be local, as the thunder storm and tornado, or widespread, as the more common cyclonic storm, which usually covers an area of several hundred miles. The majority of our cyclonic storms move across the continent from west to east, usually traveling a little toward the south in the central United States, and working back toward the north in the east. (See Fig. 85.) Our cyclonic storms therefore leave the United States in a northeasterly direction. The center of this storm area has low barometric pressure, and winds blow toward it from all directions. The warmest temperature is found at about the center of the low area. The southeast quadrant of this area is, as a rule, the one that gives the greatest rainfall or snow. The northwest quadrant is the one that gives us a cold temperature. A study of the diagram of

the storm area, and its path across the continent, will explain why a falling barometer is an indication of a probable storm; why it is warmer during a storm and colder after it; why a rising barometer indi-

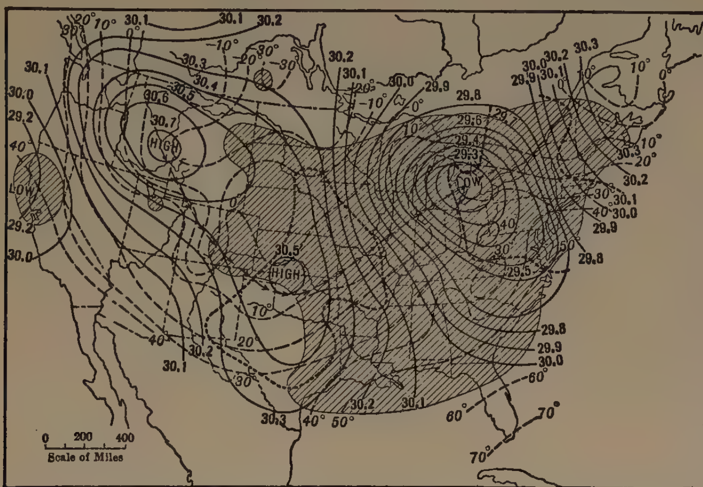


FIG. 86.—Weather map, Feb. 1. Note positions of low and high areas. Shaded areas have had rain or snow.

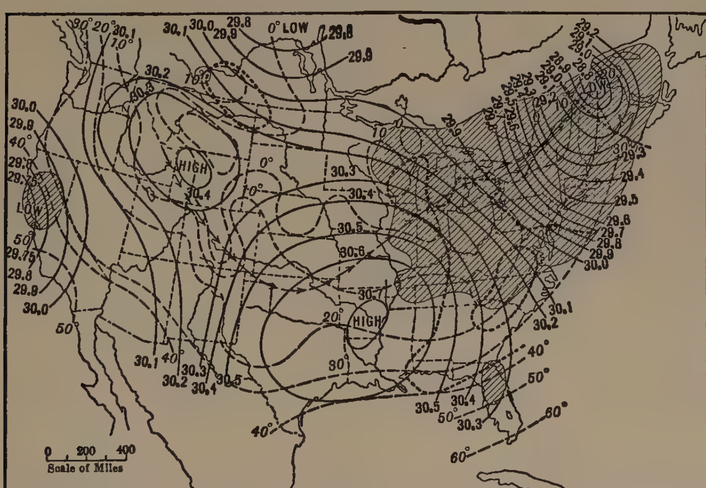


FIG. 87.—Weather map, Feb. 2. Note changed positions of lows and highs. The arrows indicate the path of the low.

cates probable fair weather; why an east or southeast wind indicates a storm; and why a northwest or west wind indicates clearing or fair weather and generally lower temperature.

Anticyclones. Alternating with the low-pressure areas of the cyclonic storms, or **cyclones,** are areas of high pressure, which are called **anticyclones.** Conditions in these areas of high pressure are contrasted with those of the low-pressure areas in Table VIII. Examine Fig. 83, and compare conditions mentioned there with those given in the table. The winds blow outward in a clockwise spiral from the high area and inward in a counterclockwise spiral toward the low area.

TABLE VIII

CYCLONES AND ANTICYCLONES

Weather Factors	Cyclones	Anticyclones
Temperature	Warm	Cold
Moisture	Moist air	Dry air
Density	Light air	Dense air
Pressure	Low	High
Wind	Blows inward	Blows outward
Air current	Ascending	Descending
Sky	Cloudy	Clear

Snow and hail. When clouds result from condensation of moisture at a temperature below freezing, the vapor forms a characteristic six-angled snow crystal, and groups of these unite to form snowflakes. (See Fig. 82.) Raindrops formed in clouds at very high levels may drop through alternate layers of warm and cold air and receive successive coats of ice. The hailstones thus formed frequently do much damage to crops.

Thunder storms. Thunder storms, unlike the storms which prevail through the larger portion of the United States, are local disturbances, being usually only a few miles in extent, and rarely covering an area with a 40-mile diameter. Cumulus clouds, those forerunners of the thunder storm, are produced by cooling of ascending air by expansion. In hot weather, numerous small areas of land get very hot and start many local ascending currents. When these reach sufficient elevation so that the air is cooled to the dew point by expansion, clouds are formed in each one of these rising columns. The rising air columns push out the first clouds formed and eventually produce a dense continuous cloud. This happens on sultry days when much moisture is in the air and the air is stagnant or perhaps there is a slight south to southeast breeze. The storm almost always approaches from the west and travels toward the east. Very strong winds develop, and usually a heavy downpour of rain follows, accompanied by electrical discharges.

You have doubtless observed that raindrops are much larger during

a thunder storm than during other storms. Drops of water, when electrified by induction, attract each other, and so a number of small drops unite to make one large one. This fact is easily demonstrated by sending a jet of water halfway to the ceiling, having it so placed that it falls into the sink. Adjust the flow of water to get a spray of fine drops. Electrify a rod of hard rubber with fur or flannel. Hold the electrified rod near the stream of rising water, as in Fig. 88. Instantly the drops increase in size very noticeably.

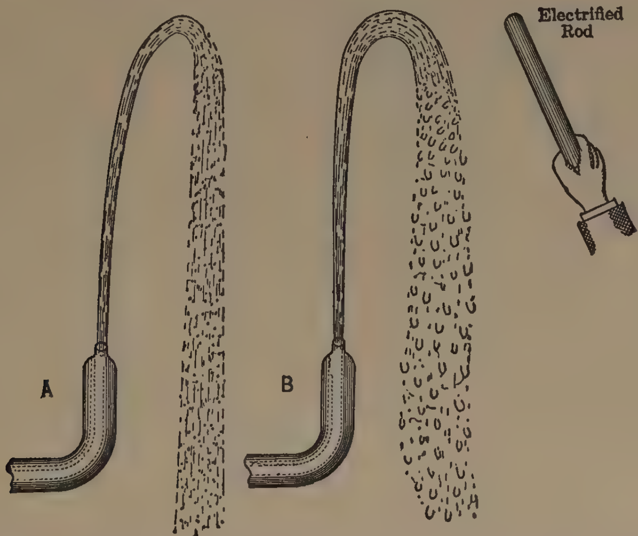


Fig. 88. — When a spray of water is electrified, the drops increase in size.

Lightning. Lightning is the characteristic accompaniment of thunder storms and electric storms. Clouds become charged with electricity, sometimes positively and sometimes negatively. The electric charges in two oppositely charged clouds, or in a cloud and the earth, attract each other, and if there is sufficient electrical pressure to overcome the resistance of the air between them a discharge takes place. In its passage through the air the electrical energy heats the air particles until they give light. This is the *lightning*. The heat causes the air to expand. After the flash and the accompanying heat and expansion, the air cools quickly and produces a partial vacuum. The greater pressure of the surrounding air forces air particles into this vacuum with great violence. The sound which is produced when these particles from opposite sides meet is *thunder*. One part of the lightning may be a mile away from you while the other part is near by. The thunder from the more distant part will reach you about five seconds later than

that from the nearer part. Thus while the flash of lightning is practically instantaneous, the thunder which you hear may be of considerable duration. Thunder may be reflected from the clouds, the ground, and layers of air of different density. Thunder from a series of discharges may overlap. Reflection and overlapping produce a characteristic rumbling, with which you are familiar.

Protection from lightning. In localities where thunder storms occur frequently, a tree standing out in the open is more likely to be struck than another tree just like it in the forest. In the forest there are so many trees with their tops reaching up toward the clouds that a silent discharge of the electricity takes place, and the relative strain or tension between earth and cloud is often so reduced that no violent discharge occurs between them. Lightning rarely strikes in thickly settled communities. This is because of the large number of objects projecting into the air, many of them metal, which are connected with the earth. They produce a silent discharge just as the trees in the forest do. It is the isolated building, flagpole, church spire, or chimney that needs artificial protection. Properly installed lightning rods have been found very effective in reducing damage by lightning and are recommended by the U. S. Weather Bureau. Lightning rods act in two ways to prevent damage. First they increase the amount of silent discharge and so to a slight extent at least decrease the likelihood of a strike; second, if there is a strike near by they furnish low-resistance paths for the electricity to the earth without harming the objects which they are used to protect. It is important that the ground end of the conductor go deep enough into the earth to connect with a layer of moist earth, since dry earth is a poor conductor. Statistics show that the percentage of fires caused by lightning is far less for buildings having lightning rods; also that where fires have been reported in rodded buildings a third of these had defective rods.

Tornadoes. Another hot-weather storm is the *tornado,* sometimes improperly called a "cyclone." With the possible exception of lightning, a tornado is the most violent of our atmospheric disturbances. It is even more local than the thunder storm, as it usually travels in a path but a few hundred feet in width. Air rises spirally at its center and flows in toward the center with high velocity, sometimes reaching several hundred miles per hour. The intense, whirling, upward current produces a partial vacuum at the center of the rising column. Moisture condenses and produces what appears as a funnel of cloud, sometimes reaching from the earth to the clouds above. The pressure within this funnel cloud may be reduced to 11 pounds per square inch, or nearly to 1600 pounds per square foot. This is a little over 500 pounds less

than the normal atmospheric pressure. Picture your own house suddenly enveloped by the funnel cloud. The pressure of the air within the house is 2100 pounds per square foot. In an instant the pressure outside is reduced to 1600 pounds per square foot. This means that an unbalanced outward pressure of 500 pounds per square foot would be applied to the walls. If one side of the house were 20 by 30 feet — 600 square feet — the force on that one side would be 150 tons and the result would be in the nature of an explosion.

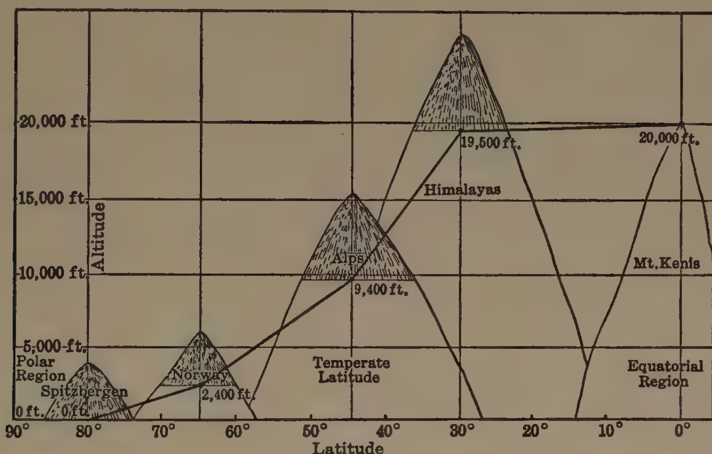


FIG. 89. — Altitude of perpetual snow line for different latitudes.

Relation of climate to latitude and altitude. As a rule, we consider that a cold climate belongs to polar regions, and a hot climate to the tropics. In general this is true, but it is not the whole truth, for within the area of the torrid zone, covering a band around the earth more than 3000 miles broad, are found all types of climate. Within this belt are the driest, as well as the most humid, areas in the world. Within this area, too, the temperature may vary from severe cold to intense heat. The tops of some of the mountain peaks reach a line of perpetual snow, while at low altitudes we find the hottest temperatures of any place on the earth. An altitude of 300 feet at the equator means a drop of about 2 degrees in temperature, and is equivalent to moving north, or south, 140 miles. It is not even true that all the arctic zone is a land of perpetual snow, and at a latitude of 65° in Alaska, within 2 degrees of the arctic circle, wheat, alfalfa, and vegetables, such as cabbages, peas, and turnips, are successfully grown.

The effect of bodies of water upon climate. The high specific heat of water gives a body of water a large heat capacity, and as a result

lakes and oceans store vast quantities of heat energy received from the sun. Under favorable conditions this heat is given to the air, and in this way tempers the climate. In some parts of the earth alternating land breezes and sea breezes result from the differences in temperature of water and land areas. Because the earth is warmed to a higher temperature than water by a given quantity of heat, the air over the land becomes hotter than the air over the water during the daytime, and the cold air from the water flows in over the land, pushing the lighter, warm air upward. The warmed land radiates heat faster than the cooler water, and as a result the land, even though hotter than the water, contains less stored energy. At night the earth, since it has less stored heat than the water, cools faster and becomes colder than the water. This results in a flow of air from land to water. In freezing weather the water gives up heat to the air, not only in cooling but also during the process of freezing. The formation of 1 pound of ice liberates as much heat as the cooling of 144 pounds of water 1 Fahrenheit degree.

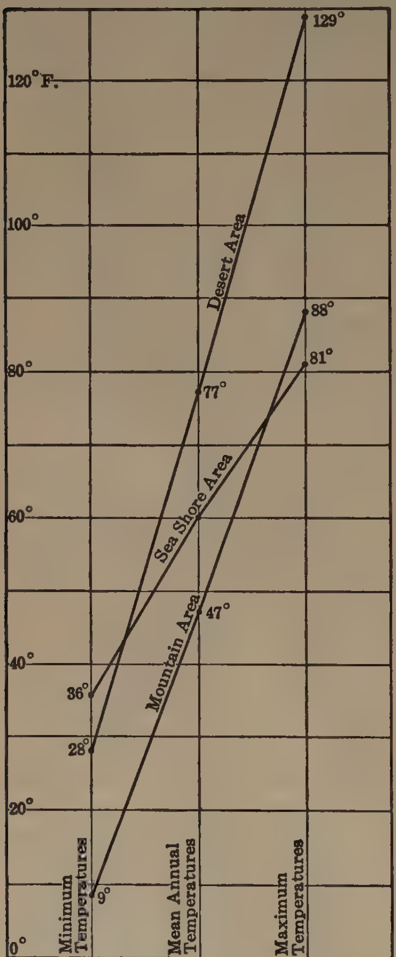


FIG. 90. — Range of temperatures in three typical regions.

In San Diego County, California, are to be found mountain, desert, and seacoast areas adjoining one another. The mountainous region has low humidity, cool winters, and warm summers, with wide variation between day and night temperatures. The seacoast region has moderately high humidity, warm winters, and cool summers, with slight variation between day and night temperatures. The desert region has warm winters, with wide variation of day and night temperatures, hot summers, with little variation of day and night temperatures, and extremely low humidity.

Advantages of variable temperatures. How often we hear someone complain about the frequent changes in temperature! If we were sure the temperature would not change we could provide clothing and shelter which would always make us comfortable. We long at times to live in a climate of even temperature. Studies of the civilization in countries where uniform temperatures are found indicate that even there conditions are not all that could be desired. The monotony of changeless temperature is very depressive. Prolonged uniform temperatures decrease one's ability to do efficient work, whereas a variable climate is found to promote both mental and physical efficiency. A drop of 4 Fahrenheit degrees is sufficient to stimulate one to greater activity. It has been found that women are more sensitive to changes in temperature than men. A fall of 8 degrees produces the same stimulation in women as a fall of 10 degrees does in men. Circulation of blood is essential to all activities. Cold baths, hot baths, and alternation of hot and cold wet cloths are found to stimulate blood circulation. It is thought that in some way alternations in temperature increase our activity and so promote efficiency.

SUMMARY

1. Weather is the resultant of various factors acting in the atmosphere, chiefly under the influence of the sun — which is the source of all energy on the earth.

2. The normal pressure of the atmosphere is 14.7 pounds per square inch.

3. The barometer is an instrument for measuring the pressure of the atmosphere. The mercurial barometer uses a column of mercury which is supported by the atmosphere, and the aneroid barometer records the pressure that the atmosphere exerts upon a metal box from which the air has been partly removed.

4. Polar air masses moving over the land are gathering moisture; tropical marine air masses supply most of the precipitation on the land.

5. Barometers for measuring atmospheric pressure are useful in weather forecasting and in measuring altitude.

6. "Saturated air," meaning saturated space, exists when a given space holds all the moisture it can hold at a given temperature. The capacity of the "air" (space) for holding moisture increases with a rise in temperature.

7. The actual amount of water vapor (grains per cubic foot) in the air is the **absolute humidity.** The ratio of absolute humidity to the capacity of the air at a given temperature, expressed in percentage, is the **relative humidity.**

8. Clouds are formed by condensation of moisture in air through cooling. The most important cause of cooling is the expansion of rising air currents.

9. Dew and fogs are formed by condensation of moisture in air near the earth's surface. Snow and frost occur when the condensation takes place below the freezing point.

10. Winds are natural convection currents. The type of wind characteristic of a given locality depends upon season, latitude, bodies of water or large areas of land, and revolution of the earth.

11. Cyclonic storms travel across the country periodically, alternating with anticyclones, or periods of clear weather. Thunder storms are local storms attended with electrical discharges. Tornadoes are storms of very limited extent, but of exceptional violence, due to the extremely low barometric pressure at the center of the funnel cloud.

12. Variable temperatures are considered better than uniform temperatures, both for health and for efficient work.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. The local weather station.
2. Weather facts and weather fallacies.
3. Electrical storms and protection against lightning.
4. Measure the height of a school building or a nearby hill with an aneroid barometer.
5. Measure the humidity of the air in the room.
6. Destructive tropical storms.

CHAPTER VIII

BOILING WATER AND STEAM

Boiling water. No process used in the kitchen is more common than boiling water. We have already seen that the temperature of the water rises when water is heated. Let us now make a more careful study of this process. Fill a 1-liter beaker three-fourths full of water from the faucet. We shall use glass in order that we may watch what goes on, and thin glass lest the heat crack it by unequal expansion. Place the beaker over a gas flame, suspend a thermometer in it, and watch for results. You will notice first that small bubbles of gas separate from the water, and many of them cling to the walls of the beaker. They are bubbles of air which had previously dissolved in the water. Their removal from the water causes the "flat, insipid" taste in freshly boiled and distilled water. After a time larger bubbles appear at the bottom of the flask. They start to rise and quickly disappear. Now these bubbles rise higher and higher, starting large and growing smaller until they, too, disappear. Soon we see vapor escaping from the surface of the water. We hear a sound which, when produced in the teakettle, is spoken of as the "singing" of the kettle. The mercury in the thermometer has been rising all this time, but the temperature has not yet reached 200° F. The bubbles which rise from the bottom of the beaker are bubbles of steam. In rising they meet cold water, which causes them to condense, and, as they disappear, the water coming together in the space which they occupied strikes many small blows, which cause the singing sound. Before long we see that a few bubbles actually reach the surface of the water, then more and more of them. As the bubbles now rise, they increase in size as they near the surface. The bubbles are not condensed any longer because the water and the steam are at the same temperature. They increase in size as they rise because the pressure of the water upon them grows less as they near the surface. As the bubbles break through the surface of the water, they produce the effect of *boiling*. These bubbles are steam, which is water in the form of gas. When the entire surface is bubbling from the escape of steam, the thermometer registers 212° F. We continue to apply the heat, and no other effect on the water is observed unless it be more vigorous boiling. The temperature remains unchanged. No matter how long we boil the water, it will get no hotter, so long as

we let the steam escape freely. This temperature, 212° F., is the **boiling temperature** of water at sea level.

Boiling temperatures. Have you not seen more automobile radiators boiling over in cold weather than in the warm summer months? Many people, in cold weather, use a mixture of water and alcohol to cool the engine. The alcohol has a low freezing point and prevents freezing in the radiator. But it also has a lower boiling point than

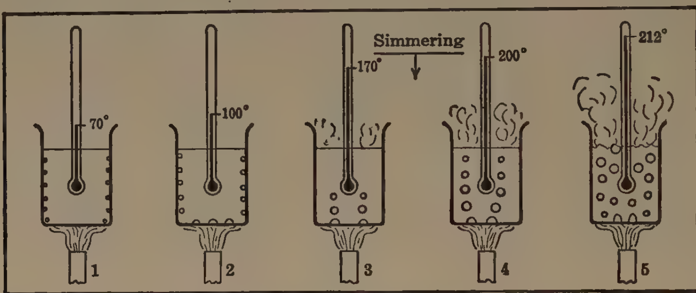


FIG. 91.—Boiling water. After reading the text tell just what is taking place in these five drawings.

water. Not only does the radiator " boil " at a lower temperature, but also the alcohol vaporizes so much faster than the water that more alcohol must be added, from time to time, to insure the same protection against freezing.

Every liquid has its own definite boiling point, which differs from those of other liquids. The boiling point of sugar sirup is higher than that of pure water. When salt is dissolved in water, the solution has a specific boiling point, depending upon the strength of the solution. A saturated solution of common salt boils at 109° C. (228° F.), and a strong solution of calcium chloride boils at 135° C. (275° F.). Extracts and fats from meat raise the boiling temperature of the liquid in the preparation of a broth or a stew.

TABLE IX

BOILING POINTS

Liquid air	—193° C.	Water	100° C.
Liquid ammonia	—38.5° C.	Turpentine	160° C.
Ether	35° C.	Glycerin	290° C.
Alcohol	78° C.	Mercury	357° C.

Vaporization. Vaporization is a term applied to the process of changing from the liquid to the gaseous state. Water vaporizes during the **boiling process**; it also vaporizes to some extent at all temperatures.

When water or any other liquid changes to a gas at a temperature below its boiling point, the process is called **evaporation.** Evaporation can take place only at the expense of heat energy. The higher the temperature, the greater the amount of the evaporation.

Since pressure on the surface tends to prevent the passage of molecules of liquid from the surface, it follows that increasing the pressure lessens, and decreasing the pressure promotes, evaporation. Evaporation is greater from a large than from a small surface. The degree of saturation of the air above the liquid also influences the rate of evaporation. Moving air removes moisture and brings less-saturated air in contact with the surface of the liquid, and so a wind promotes evaporation. Clothes on the line dry quickly on a windy day, as do also wet pavements. Evaporation takes place even at temperatures below the freezing point of water. A block of ice is found to diminish in weight even if kept at a temperature below 0° C., and it is a common experience that clothes hung on the line in cold weather freeze and dry without thawing.

Distillation. A city water supply may be purified by filtering and the addition of chlorine to kill the germs. Boiling water will also kill germs, but ordinary water is made chemically pure only by distillation. **Distillation** is the process in which a liquid is changed to a gas and the gas condensed back to a liquid. When impure water is boiled, gaseous impurities contained in it pass off quickly. This product can be discarded. The pure steam is then condensed and yields pure water. The solids in water are left behind. When two liquids are heated, the one with the lower boiling point passes off first, mixed with a small amount of the other liquid. The condensed liquid is called **distillate.** By redistilling the distillate obtained from two mixed liquids, a purer distillate will result. This process, called fractional distillation, is used to separate alcohol from water and to separate the various products — gasoline, kerosene, or fuel oil — from crude petroleum. A **still** consists of a **retort** in which the liquid is boiled and a **condenser** in which the vapors are condensed.

Relation of the boiling point to pressure. In order to escape as gas, the steam must push the air aside. What would happen if there were less air and so less pressure on the surface of the water? What would happen if the steam were held back by a tight cover which increased the pressure? Would the steam go off just the same, and would the boiling temperature be the same?

We have already learned that the normal atmospheric pressure at sea level is about 15 pounds to the square inch and that on high mountains and other high elevations the pressure is less. The pressure upon the

surface of water which we are heating may be increased by preventing the escape of steam. Decreased pressure may be obtained by going to a higher elevation or by pumping out the air and steam. We can easily learn the relation between the boiling temperature and pressure by the demonstration which follows.

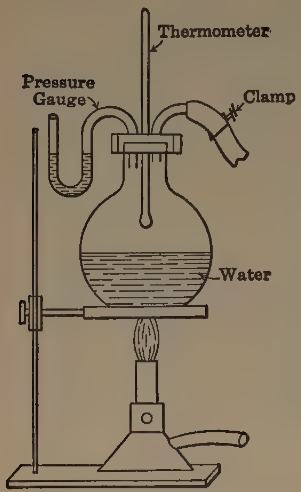


Fig. 92.—Apparatus for showing the relation of boiling point to pressure.

Heat water in a strong glass flask, fitted with a thermometer, pressure gauge, and outlet tube, as shown in Fig. 92. When the thermometer indicates 180° F. (80° C.), attach the rubber tubing to an exhaust pump or aspirator, to lower the pressure on the surface of the water. Observe the difference in mercury levels in the pressure gauge, and also note the temperature when the water boils. Disconnect the exhaust pump and continue heating until boiling begins. Have you observed that you cannot see the steam in the flask? Steam is invisible. Boil the water slowly. When the mercury columns are at the same level, read the thermometer. This reading is the boiling temperature for the atmospheric pressure at the time. Read the barometer to learn what this pressure is. Now partly close the pinchcock so that steam cannot escape as fast as it is generated. When the temperature reaches 220° F. (105° C.), measure the difference in mercury levels in the gauge tubes. Remove the flame at once.

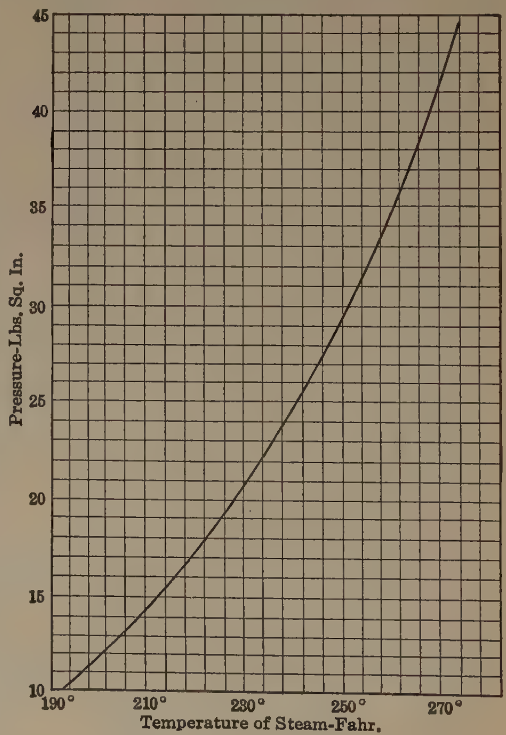


Fig. 93.—Relation of the boiling temperature of water to pressure.

The drop in the boiling point with rise in altitude is indicated in Table X. The curve of Fig. 93 shows the rapid rate at which the temperature rises with increase of pressure. The boiling point of water at different pressures has been carefully determined by experiments, and the results are given in Table XI.

TABLE X

RELATION OF BOILING POINT TO ALTITUDE

Altitude, Feet	Barometer Reading, Centimeters	Boiling Point of Water, Degrees Fahrenheit
0	76.0	212
1,000	73.2	210
5,000 (Denver)	63.5	203
10,000	52.8	194
14,000	17.9	187

TABLE XI

BOILING POINT OF WATER AT DIFFERENT PRESSURES

Pounds per sq. inch	Barometer Reading in Centimeters	Boiling Point	
		Degrees Centigrade	Degrees Fahrenheit
0.09	0.46	0	32
0.34	1.75	20	68
1.00	5.17	39	102
7.35	38.00	81	178
10.00	51.70	90	193
14.13	73.00	98.88	210
14.32	74.00	99.26	210.7
14.51	75.00	99.63	211.3
14.70	76.00	100	212
14.89	77.00	100.37	212.7
15.08	78.00	100.73	213.3
20.00	103.40	109	228
30.00	155.10	121	250
40.00	206.80	131	267
50.00	258.50	138	281
250.00	1292.50	208	406

Boiling under normal pressure. Much cooking is done in boiling water, in vessels which are open or loosely covered, so that the temperature of the water is around 212° F. When cold, raw food is put into boiling water, it absorbs heat and the water is cooled. A cold egg dropped into a cup of boiling water on the stove will stop the boiling and reduce the temperature several degrees. When cereals are cooked in boiling water, thickening prevents convection and increases the danger of burning. For such cooking, the double boiler is useful. Steam has the same temperature as the boiling water from which it comes, and, since a large part of the food compartment of the boiler is surrounded by steam, it is almost as hot as if the contents were actually boiling. The double boiler is a type of steam cooker.

FIG. 94. — Vacuum pans in which water is removed from sugar by boiling under reduced pressure.

Boiling under low pressure. No practical use is made in the household of boiling at pressures below normal, and yet we use products which have been prepared under low-pressure boiling temperatures. One of our common staple foods, sugar, is crystallized from solution in huge vacuum pans. It is impossible to drive the water off at normal pressure without changing some of the sugar chemically. When the pressure on the solution is reduced to one-half an atmosphere, water will boil at 178° F. The temperature of the solution in the vacuum pans is kept at about 150° F. to 160° F. by regulating the amount of vacuum. Condensed milk and evaporated cream are food products prepared by evaporating some of the water from skimmed milk and milk, respec-

tively, in a partial vacuum. Boiling milk under normal conditions would change the composition and the taste of the milk much more than boiling it at a lower temperature under reduced pressure. The removal of water from other foods is sometimes accomplished quickly at high temperatures, or more slowly under reduced pressures. Egg powder, milk powder, and dehydrated vegetables are products from which the water has been removed as a means of preserving them.

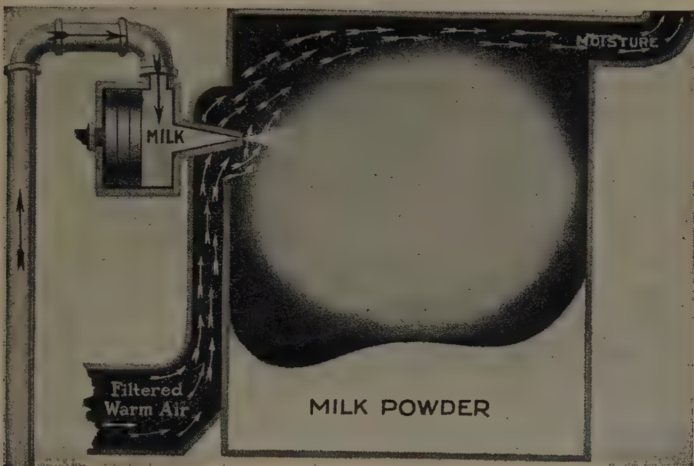


FIG. 95. — Milk powder is produced by vaporizing the water in a chamber through which a stream of warm air is constantly moving. The milk is introduced as a fine spray of vapor.

Pressure and changes in state. We are familiar with the fact that water will boil under reduced pressure at temperatures below 212° F. Water in a vacuum has been boiled at 32° F. or at a temperature as low as that of ordinary freezing. We are likely to think of the temperature at which ice is formed as fairly constant. This is due to the fact that natural changes in pressure have less effect upon the freezing point than they do on the boiling point. Dr. P. W. Bridgman of Harvard University, however, has been able, by means of extremely high pressures, to produce ice so hot that you could not hold it in your hand. He has made ice at 180° F. under a pressure of 290,000 pounds per square inch.

The steam cooker. Many vegetables and meats are cooked in water, steam, or water and steam, at 212° F. The steam cooker is a very efficient device for cooking. A food may be cooked in steam as effectively as in water, with the advantage of losing less of the extracts, which would dissolve if cooked in water, and with less danger of

sogginess in starchy foods. In the steam cooker, water is in the bottom compartment which sits upon the stove. The steam rises and may pass through several compartments which contain different foods. The cooker is tightly covered, so that very little steam escapes. After the cooker and contents are once heated to the temperature of steam, it requires very little fuel to keep the contents cooking. Steam must be produced fast enough to replace that condensed on the walls of the cooker, and to give up enough heat to make up for what is lost by radiation, conduction, and convection from the outside surface of the cooker. But there is much less waste of heat from escaping steam than there is when boiling is done in an open or loosely covered kettle.

The pressure cooker. Boiling water has a temperature of 196° F. on Pikes Peak and of 202° F. in Denver. It requires a longer time to cook vegetables and meats in boiling water at high elevations than it does at sea level. It is therefore advantageous, in high altitudes where the pressure is low, to cook vegetables and meats under pressure, although at lower altitudes these foods would be cooked in boiling water or free steam. When a vessel containing boiling water is closed to prevent the escape of steam, great pressure results and a rise in temperature follows. Such devices, called *pressure cookers*, are frequently used to secure a higher temperature. At 5 pounds per square inch pressure (above atmospheric pressure) a temperature of 228° F. is obtained; at 10 pounds, 240° F.; and at 15 pounds pressure, 250° F. Not only does this cooker find favor in high altitudes, but in any section of the country it enables us to cook foods more quickly, with a consequent saving of fuel. Certain tough cuts of meat, which are not desirable food when cooked at 212° F., are tender and palatable if cooked at the high temperature obtained under 15 to 20 pounds pressure.

Fig. 96. — A pressure cooker.

Another useful application of the pressure cooker is in canning fruits and vegetables. Most vegetables and some fruits are scalded or blanched in boiling water, and then dipped into cold water. They are then canned and placed in the pressure cooker. Asparagus requires 40 minutes' cooking under 5 pounds pressure or 30 minutes under 15 pounds

pressure. Peaches require 10 minutes at 5 pounds and 5 minutes at 15 pounds pressure. Sterilizing can be done more efficiently at the high temperature of the pressure cooker. The extraction of gelatin and glue from bones is accomplished under a pressure of 10 to 20 pounds, in extractors which are in principle like the pressure cooker. The time-saving value of the pressure cooker is shown by Table XII.

TABLE XII

TIME REQUIRED TO COOK FOODS

	Open Vessel Cookery	Steam Pressure Cookery
Pork and beans	3 Hr.	40 Min.
Ham	4 Hr.	50 Min.
Pot roast	2 Hr.	50 Min.
Meat soups	2 Hr.	30 Min.
Chicken	90 Min.	30 Min.
Cabbage	40 Min.	10 Min.
Potatoes	30 Min.	10 Min.
String beans	50 Min.	15 Min.
Steamed puddings	30 Min.	10 Min.

Popped corn is pressure-cooked. Popcorn has a very hard non-porous shell. The soft content inside is moist. When heat is applied quickly, the water inside cannot escape readily and is heated above its normal boiling temperature of 212° F. It is thus under pressure and cooks the starch granules just as if they were in a pressure cooker. The continued addition of heat keeps increasing the pressure inside the kernel. Finally, the resistance of the shell is overcome, and in the resulting explosion (popping) the kernel is turned inside out, and the white, fluffy, cooked starch granules appear greatly expanded in size and made porous by the sudden expansion of enclosed steam. Popcorn kept several years may lose so much water that it will not pop well. Fresh popcorn under a year old is best.

This principle is applied in producing puffed wheat and puffed rice, but, since their shells are not so compact as those of the corn, they have to be placed in iron cylinders, also a type of pressure cooker. After the internal water pressure has reached the desired point, the cylinder is suddenly opened and the kernels "puff."

The waterless cooker. The waterless cooker is made of aluminum. The cover clamps on air tight. It is never placed directly over the flame but stands upon a steel base. This base keeps direct heat from

the bottom of the cooker and prevents the food inside from burning on. Foods — vegetables, fruits, and meats — contain enough water for proper cooking. When the water from the juices has reached slightly more than the boiling temperature the pressure of the steam opens a valve in the cover. This is taken as the beginning of the cooking temperature. The heat is then turned down and the valve closes. At this low heat there is no further loss of water. The steam is condensed on the walls inside the cooker and runs down to the bottom where it is vaporized again, keeping the food surrounded by steam all the time. Several foods, each in a separate dish, or meat and vegetables in the same container, may be cooked at the same time. The cooker may be used for canning by the cold-pack method and for making preserves. Because of the base of the cooker no stirring is needed and fruits keep their natural shape.

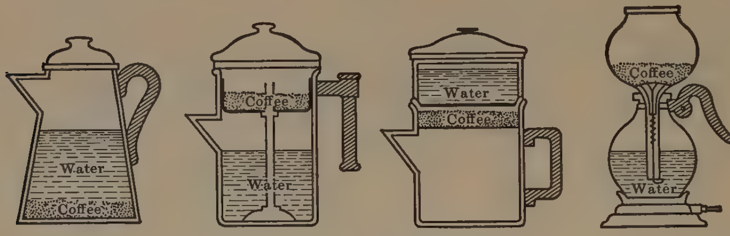


Fig. 97. — Coffee-making devices.

Coffee-making devices. Four types of coffee-making devices are in common use. The old-type **coffee pot** in which the coffee grounds are boiled right in the water is still used. Some people put the shells of freshly opened eggs into the coffee to "settle" it. The albumin on the inside of the shell coagulates and as it settles takes down the fine sediment of the coffee grounds.

The **percolator** has had much favor but now is yielding to newer devices. The percolator operates upon a simple principle. It owes its geyser-like action to the production of steam under greater than normal pressure. It is a geyser in miniature, and is as regular in its periodic spoutings as the natural geysers themselves. One often wonders to see the action begin within a minute after heat is applied and while the water is still cold. A small body of water is separated from the rest in a reservoir at the bottom of the percolator. A tube extends from the top of this chamber to the space above the coffee at the top of the percolator. Water in the chamber receives direct heat and keeps it, since, enclosed as it is, it cannot set up convection currents throughout the entire liquid. For this reason, boiling water is pro-

duced in the enclosed chamber, while the outside water is comparatively cold. The column of water in the tube causes sufficient pressure to raise the boiling temperature a little above the normal boiling point. In some percolators there is a valve to the percolating chamber. When steam forms, it exerts pressure which closes the valve, and then the only escape is through the tube; but this tube contains water, which is forced out by the steam. As soon as this happens the pressure is reduced; then the pressure of the water on the outside of the valve opens it, and the percolating chamber is filled with water again. The heating of this water and the resulting flow from the tube are repeated periodically. Some percolators have no valve, but have a very small inlet for the cold water to enter. In the rapid movement of water when steam is suddenly produced in quantity, very little of it escapes from the chamber through the small inlet spaces, while the greater part of it is blown up through the tube.

The **drip method** has a pot in three parts. The top section, having very small holes in its base, holds boiling water. This drips slowly upon the finely ground coffee in the middle section. The water stays in contact with the coffee long enough to make an extract and then slowly drips through holes into the bottom storage compartment.

For **vacuum filter method,** the device has two chambers. The top chamber has a tube running down nearly to the bottom of the lower chamber. When they are placed together the connection between them is air tight. A filter covers the opening at the base of the top chamber. Very finely ground coffee is placed in the upper chamber. The lower chamber, of heat-resisting glass, holds the water. The two parts are put together and heat applied. When the water produces steam, pressure results on the surface of the water since it has no outlet. As a result the water is pushed up the tube into the upper compartment where it covers the coffee grounds. The heat is now shut off. As the steam in the lower compartment condenses, a partial vacuum is produced and the liquid runs back into the lower compartment. If stronger coffee is desired the liquid may be run through a second time or it can be left with the grounds longer by keeping the heat on longer. Study the diagrams (Fig. 97) to understand just how each device works.

Preserving foods. Ever since man has lived in a permanent home, he has experienced the need of keeping food from spoiling. The early methods were drying and use of such preservatives as spices. The more recent methods are canning and refrigeration. The chief cause of spoiling of food is the action of microorganisms, for example, wild yeasts, molds, and bacteria. The use of heat in preserving foods is important in many large commercial industries. Microorganisms must

have heat, food, and water to thrive. Removal of any one of these three checks their development.

Drying foods. Drying is probably the oldest method of preserving foods. It was practiced by the ancient Egyptians. The American Indians dried fish, meat, and fruits both by the sun and over fire. The cowboys of the Western plains formerly had their "jerked beef," which was only beef dried in the sun. "Hardtack" is a dry biscuit used by armies. Drying removes water, one of the essentials of germ growth. We have in our markets dried fruits, as prunes, raisins, figs, apricots, apples, and peaches. The three last named are usually sliced before

Ewing Galloway.

FIG. 98. — Apricots drying in the sun in California. A long season without rainfall makes this possible.

drying. We also have powdered eggs and powdered milk, produced by drying. Dried fish and dried beef are found in our markets today beside the fresh meats.

Dehydration. The process of preparing dried or "evaporated" foods is commonly carried on at ordinary temperatures and pressures, but with relatively dry air. This process damages the delicate fibers and food tissues, so that toughness, flatness of taste, and some loss of food value result. An improved method of taking the water out of foods, especially fruits and vegetables, is known as **dehydration.** In this process the fruit or vegetables are subjected to the action of moving hot air, which has a predetermined amount of moisture in it. Under the action of the heat in the presence of the moist air, the water leaves the cells of the food without injuring the tissues or destroying the flavor.

Dehydration is an improvement over ordinary drying because, when water is supplied to the dehydrated food, it regains its original appearance and flavor to a much greater degree than do foods dried by other methods.

Canning. During the period in which Napoleon was trying to conquer the world, the need of preserving foods was great. François Appert won a prize of 12,000 francs for suggesting and developing the process of preserving food by canning. He placed the food in glass-covered jars and cooked it by immersing the jars for a time in boiling water. The bacteria were killed, and then the covers were sealed so that no other bacteria could enter. Boiling for five minutes will kill many germs. Twenty minutes will kill most germs. There are, however, spores that will survive even that. If a resting period is given after the boiling, long enough for the spores to start to develop, a second boiling will kill them. Most fruits canned after a single period of boiling will keep, but some of the vegetables require much longer cooking unless a temperature above 212° F. is used. A higher temperature may be secured with the pressure cooker. In commercial canneries temperatures above 212° F. are used.

Heat of vaporization. We have seen that, when water is at the boiling temperature, additional heat does not increase its temperature; instead, it increases the internal molecular energy and causes the liquid to change to a gas. The resulting steam has the same temperature as the boiling water. It is possible to find approximately the amount of heat absorbed in this change of state by the following experiment. Secure two dishes of the same kind and size, holding about half a liter. Pour into one 20 grams of water at 20° C., and pour into the other 300 grams of water at the same temperature. Place these dishes on the stove at the same time, so that they will receive equal amounts of heat. Stir the 300 grams of water at intervals with a thermometer. Do not let the thermometer bulb rest on the bottom of the dish at any time. At the very instant that the 20 grams of water has entirely vaporized, take the temperature of the 300 grams of water.

In one experiment the temperature of the 300 grams of water rose from 20° C. to 61° C. The amount of heat absorbed was $300 \times 41 =$ 12,300 calories. If we may assume that both bodies of water received equal quantities of heat, then the 20 grams of water has absorbed 12,300 calories, but it has absorbed them in two processes: (1) in being warmed from 20° C. to 100° C.; (2) in changing from water into steam at 100° C.

In changing from 20° C. to 100° C., $20 \times (100 - 20)$ or 1600 calories were absorbed. There remain $12{,}300 - 1600$ or 10,700 calories.

absorbed in the process of changing state. One gram of water would then have absorbed 10,700 ÷ 20 or 535 calories. Different experimenters have obtained different numbers, ranging from below 534 to above 540 calories. Let us take an average, say 537 calories, as the amount of heat required to change 1 gram of water at 100° C. into steam at 100° C.

The heat of vaporization of water is 537 calories per gram. In English units, the heat of vaporization is 965 *B.t.u. per pound.*

Whenever 1 gram of steam condenses at 100° C., it gives up 537 calories of heat, and the resulting water is at the same temperature as the steam. This explains why a burn by steam is so much more severe than one by hot water. As long as steam remains in a gaseous state it holds the heat of vaporization stored in it. This makes it practical to use steam in heating distant rooms. It is only necessary to allow the steam to condense in the radiator in the room to be heated, and this latent and stored heat will be given up.

PROBLEMS

1. How many B.t.u. will be liberated in a radiator by the condensation of 15 lb. of steam?
2. How many calories are required to change 25 grams of water at 40° C. into steam at 100° C.?
3. Compare the quantities of heat set free:
   (*a*) When 10 grams of water at 100° C. are cooled to 80° C.
   (*b*) When 10 grams of steam at 100° C. are changed to water at 80° C.

How do these results explain the relative severity of burns received by hot water and by steam?

SUMMARY

1. Evaporation is the change of a liquid to a gas, at the surface of the liquid. Boiling is the change of a liquid to a gas within the liquid, so that bubbles of gas must rise through the liquid to escape.

2. The boiling point of a liquid is the highest temperature to which the liquid can be warmed without increasing the pressure upon it. At this temperature it passes rapidly into the gaseous state.

3. Distillation is a process of purifying a liquid by vaporizing it and then condensing the vapor. Fractional distillation is the separation of two liquids having different boiling points.

4. The boiling point of a liquid is lowered by a decrease in pressure, and raised by an increase in pressure.

5. Steam has the same temperature as the water from which it comes. Steam is a valuable cooking agent in the steam cooker, double boiler, and pressure cooker.

6. The coffee percolator makes use of the pressure of confined steam to force the jets of water over the coffee, through which it sinks, taking with it the soluble extracts.

7. Foods are preserved by drying, canning, and dehydrating.

8. Dehydration is the process of removing water from foods without injuring the tissues and without destroying the flavor. It is an improved method of drying foods.

9. It requires 537 calories to change 1 gram of water at 100° C. to 1 gram of steam at the same temperature. In other words, 537 calories is the heat of vaporization of water.

10. The liberation of the heat of vaporization, when steam condenses, makes possible the use of steam in our steam heating systems.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Cooking with steam.
2. Domestic and commercial canning.
3. Determine the heat of vaporization of water.
4. Operation of different types of coffee-making devices.
5. The sugar-refining process.

CHAPTER IX

COOKING PROCESSES AND COOKING DEVICES

Methods of cooking. There are four important ways of cooking foods. (1) *Boiling*. Foods are cooked in boiling water or steam at 212° F. or in pressure cookers at higher temperatures. (2) *Broiling*. The food is subjected to intense radiant heat from flame, hot coals or electric unit. (3) *Frying*. Frying is done either with a small amount of fat or in deep fat in which the food is immersed. (4) *Baking*. Generally baking is started at high temperature and then the temperature is reduced to give time for the heat to penetrate to the center of the food. This is especially true of roasts when the first intense heat sears the surface by coagulating the proteins and thus prevents the loss of juices.

Cooking ranges. There are three types of cooking ranges, namely: the coal or oil range, the gas range, and the electric range. Besides these, many homes have a number of supplementary devices either for home or camp use. There are small oil and gasoline stoves. There are electric grills, sandwich toasters, and waffle irons. Except for the expense, electric heat is most desirable because of its cleanliness and being always ready for use. In many communities the rates for electricity are low enough for economical use of the electric range.

The coal range. The ordinary kitchen range for burning coal has a small *firebox* lined with fire clay, an *ash pit*, and an *oven*. The burning of the fuel is regulated by controlling drafts and dampers. The main air supply enters through the draft into the ash pit under the coal, and passes through the layers of coal, where it aids combustion. The hot gases, coming from the burning coal, pass directly to the chimney through the stovepipe, or around the oven and then to the chimney. There is a *check draft* which admits air directly to the firebox above the coal. A *damper*, and frequently a check draft, which may be used to check the fire, are placed in the stovepipe. An *oven damper*, if raised, causes the hot gases to pass around the oven before entering the stovepipe. When the oven damper is down (open), the hot gases pass directly to the stovepipe. The damper has one or more small holes in it so that some gas may pass through when it is shut. This is essential, for if it closed the pipe completely there would be danger of poisonous carbon monoxide escaping into the room. This gas is often produced

abundantly for a short time just after fresh coal is added, and even with the perforated damper some of it may escape into the room if the damper is closed too soon after adding the coal. This is the cause of many deaths by asphyxiation from the so-called "coal gas." Much cooking is done on top of the stove. Covers can be removed and a vessel placed directly over the burning fuel to secure quicker heating or a hotter temperature. A long, narrow door at the side and top of the firebox may be opened for the purpose of broiling.

Oven temperature. The oven is heated by hot gases, which are compelled to encircle it. The oven temperature may easily be regulated by the strength of the fire and by means of the various controls. Opening the oven door will rapidly cool a hot oven. The oven temperature is influenced by other uses of the range. If much water is heated by

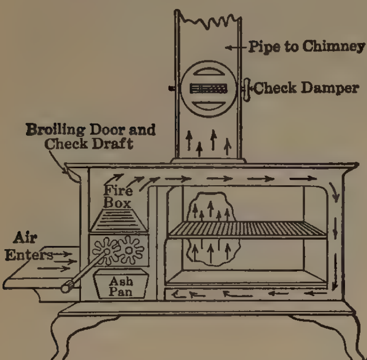


FIG. 99. — *A*. The coal range. *B*. Oven damper.

the range for the hot-water supply, or if the top flue above the oven is used as a hot plate, much heat will be taken away which would otherwise go to the oven.

An oven door with a glass window is convenient for observation of the temperature and the progress of baking. A mercury oven thermometer is more accurate than the usual metal thermometer attached to the oven door. These mercury thermometers are so made that they will stand in the oven and may easily be read through the glass window.

Control of oven temperatures. The experienced cook knows that the oven temperature is just as important as using the right ingredients in food. The need of a slow, a moderate, or a hot oven is felt instinctively as she prepares the food. Too much heat causes milk and eggs to coagulate and "whey," that is, the curd separates from its watery surroundings. A slow oven, or even setting the custard in a pan of water in the oven, will help to keep the temperature down. Slow heating of a piece of meat drives the liquids out and results in a dry roast which lacks flavor. A very hot oven at the beginning of the roast-

ing, by coagulation and other chemical changes, closes the surface pores so that a lower heat may then be used to complete the cooking without loss of the juices which keep the roast moist and give it flavor. Modern gas and electric ovens have thermostatic control which can be set at any desired temperature.

TABLE XIII

REGULATION OF THE COAL RANGE[1]

For	Draft to Ash Pit	Check to Fire-box	Damper in Stove-pipe	Check in Stove-pipe	Oven Damper
Starting a fire	Open	Closed	Open	Closed	Open
Cooking on stove, rapid	Open	Closed	Open	Closed	Open
Cooking on stove, slow	Closed	Closed	Partly open	Partly open	Open
Cooking in oven, rapid	Open	Closed	Open	Closed	Closed
Cooking in oven, slow	Closed or nearly closed	Closed	Partly open	Closed	Closed
Cooling overheated stove and oven	Closed	Open[2]	Open	Closed	Open
Keeping fire over night	Closed	Open	Closed	Open	Open

[1] Slight variations from these regulations may be found to give better results according to the stove used. Experience alone can give you the best regulation for a given stove, since in two stoves of the same style and make there will be some variation in the leakage around the drafts, checks, and dampers.

[2] Also open a cover on top of firebox. A large volume of cold air will pass in above the coal, absorb heat, and pass out the chimney, thus cooling the stove.

Range oil burners. There are oil ranges and there are oil burners which can be installed in the firebox of a coal range. In both the oil is vaporized and the equivalent of a gas flame is produced. In one type of oil range an asbestos wick absorbs the oil, which begins to vaporize immediately. Air enters through the perforations in the different metal sleeves. After burning for a time, the heat vaporizes so much of the oil that a gas flame is produced entirely above the wick. These burners need care to keep them in good working order. Especially must all carbon and dust be cleaned from the air holes. The products of combustion are carried off through the stovepipe and chimney.

The oil reservoir. A reservoir supplying oil to the burner is usually supported on a rack near the range. Two scientific principles are involved in the action of oil delivery. A bottle holding several gallons is inverted in a small tank. When oil in this tank reaches the mouth of the bottle, the flow stops. The oil is held up in the reservoir by

atmospheric pressure on the surface of the oil in the tank. No more oil can run out until the oil is used up, and the level in the tank is lowered enough to let a bubble of air enter the reservoir; then oil runs out to seal the mouth of the reservoir again. When the reservoir is refilled and replaced, a valve in the mouth of the reservoir closes the opening. When lowered into the tank, a projecting rod is pressed up as it

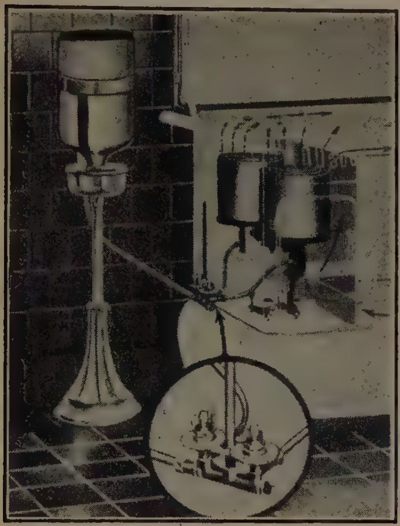


Fig. 100. — The range oil burner.

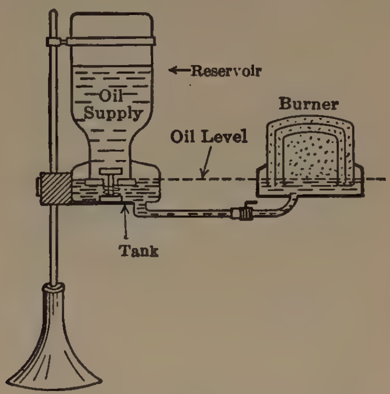


Fig. 101. — Section of oil burner.

touches the bottom of the tank, and the valve is opened, letting the oil come into the tank.

A pipe leads from the tank to the burner. The tank must be adjusted to such a height that the level of the oil surface in the tank and in the burner is the same. The oil is delivered to the burner on the principle that a liquid seeks its own level.

The Bunsen burner. The Bunsen burner is devised so that gas and air can be well mixed before they begin to burn. Gas is sent through a small orifice into a mixing chamber. Openings near the base of this tube permit air to enter and mix with the gas. When the gas is lighted at the top of the tube, more air comes to the flame, permitting complete combustion. An inner cone of unburned gas can be seen at the top of the mixing tube. This gas has not yet been warmed to the kindling temperature. The hottest part of the flame is between the tip of the inner cone and the upper tip of the flame. If the air holes are closed there is insufficient air and a yellow smoky flame results. If the gas supply is

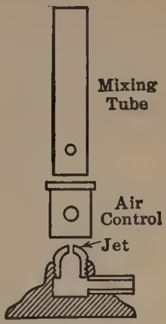


Fig. 102. Bunsen burner.

diminished too much, an explosive mixture results and the flame "strikes back" and burns within the burner tube. It must not be allowed to burn this way.

The gas range. The gas range not only is a great convenience, but also may be an economy if intelligently operated. Its cleanliness and

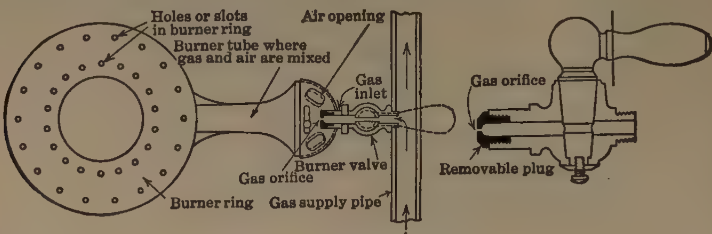


FIG. 103. — The gas burner.

readiness for instant use make a strong appeal, and in most houses the gas range is the most important gas appliance. It is necessary to understand the proper use of gas and the care of gas appliances, in order to keep these appliances in good working condition and thus make the gas an efficient means of cooking.

Location and connections of gas range. The ideal place for the gas range is where the cooking surface has good natural lighting in the day-

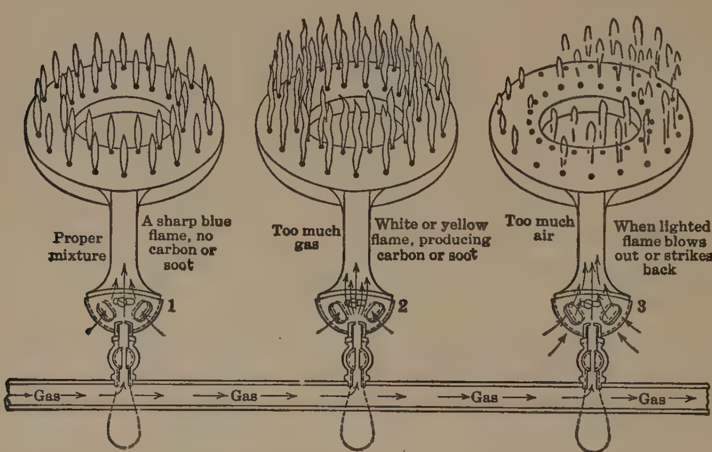
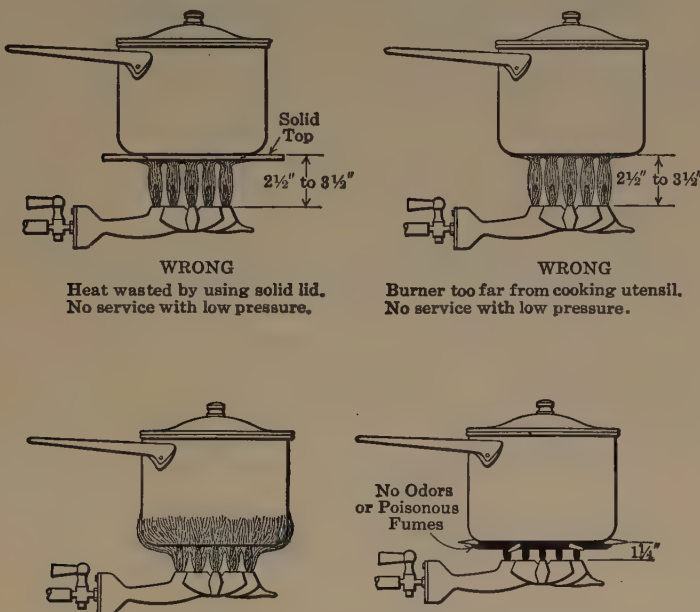


FIG. 104. — (1) Proper gas mixture. (2 and 3) Improper gas mixture.

time and good artificial lighting at night and on cloudy days. It is better to have a flue connection back of it to carry off the burned gases. It must set level so that foods will not run over on one side. The length of the legs usually can be adjusted. The sure way to know whether

the range is level is to use a carpenter's level. It is desirable to have a shutoff in the gas pipe before it connects to the range. This facilitates shutting off the gas when valves or orifices are cleaned or adjusted.

While the flue connection is not always made, the advantage is in removing odors. Baking and roasting oven odors will be discharged into the flue if one is connected. When the discharge is in the room, the room is heated by the hot gases. This is objectionable in the



WRONG
Heat wasted by using solid lid.
No service with low pressure.

WRONG
Burner too far from cooking utensil.
No service with low pressure.

WRONG
Gas turned too high.
Odors, poisonous fumes, waste of gas.

CORRECT
Cooking utensil on grate, one and one quarter inch above burner, with flame just reaching bottom of utensil. — Good service with low pressure.

Fig. 105. — Right and wrong use of gas.

summer time. The humidity is also increased by discharge into the room.

Steel wool or other filters should not be used to remove grease and keep the walls clean, because they obstruct passage of the gases and may produce improper combustion.

Top burners. There are two types of top burners, both of which make use of the Bunsen-burner principle. One of these has the burner ports on the top of a spider-shaped head. Air comes up the sides of the burner arms and through a center opening. The other has a cylindrical head and burner ports are on the side of the burner just below the top.

Both these burners have a mixing chamber where air and gas mix before reaching the burner head. The size of the orifice regulates the gas flow, and the air shutter regulates the amount of air. These must be so adjusted that the small flames at the burner ports are without yellow color and show a well-defined inner cone. Not enough air should be admitted to allow a flame to strike back into the mixing chamber, even

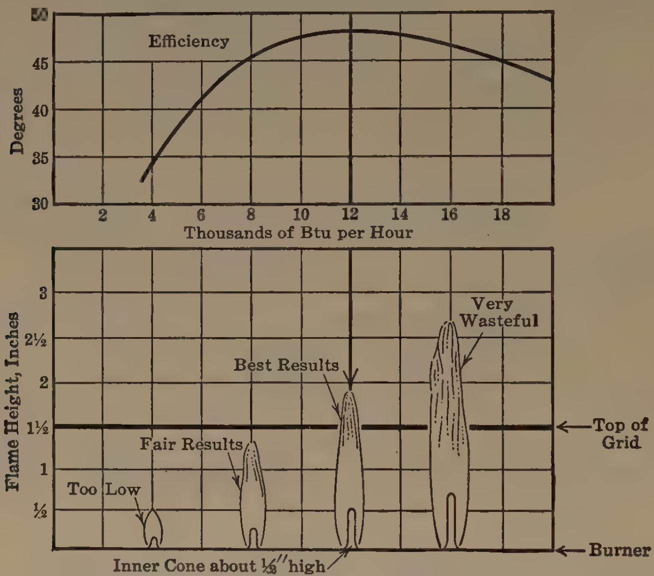


Fig. 106. — Graph for a giant top burner.

when the gas is turned low. If too little air is admitted, the flame will be yellow and will produce soot. The burner may smoke if it is dirty, if the air mixer is clogged, or if the shutter is accidently closed.

How to light the gas burner. Bring a lighted match or long taper 2 inches away from the burner. Turn on the gas full. Wait a full second, then bring the flame to the burner ports. If the flame is brought to the burner too quickly the flame may strike back and burn in the mixing chamber. When this happens shut the gas off at once.

Push-button pilot. In the older types of ranges the lighters for top burners are mostly of the push-button type. A small flame about $\frac{1}{8}$ inch tall burns all the time inside a metal hood which has holes on the sides towards the top burners. When one presses the button, more gas is admitted through the pilot tube and long tongues of flame shoot out to each of the burners. Most of the trouble with these pilots results from not keeping them clean. One should clean the burner tip and the hood periodically rather than wait until they do not work.

The automatic pilot. The new-type gas ranges have many different devices for lighting the burners automatically when the gas is turned on. Most of these are different ways of using a *flash tube.* One type of flash tube works as follows (see Fig. 107). When the gas has been turned on and reaches the burner, an opening to the flash tube lets some

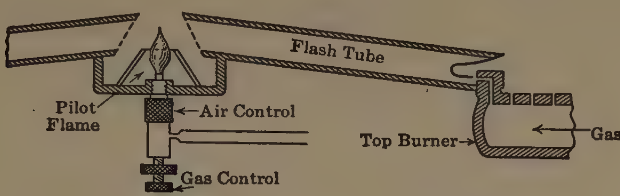


FIG. 107. — Automatic gas lighter.

of the gas mixture pass through the flash tube to the pilot flame. The flame flashes back to the burner and ignites the gas. A flash tube extends from the pilot flame to each of the top burners.

Care of top burners. Burners will need attention often if foods are allowed to boil over upon them. Under good conditions, brushing the top with a stiff brush and cleaning the primary air inlet once a month is sufficient. If the holes have become badly clogged, the iron burners may be boiled in water having a tablespoon of washing soda to each two quarts of water. Dry thoroughly before using. The soda would injure enameled and aluminum burners. The grease must be washed from these with soap and warm water. The holes may need cleaning out with a stiff wire.

Gas saving. Violent boiling does not hasten cooking. If one will turn the gas down as soon as boiling begins, gas will be saved. Less gas is required to keep up gentle boiling. When a lid is used the lid causes condensation of much of the steam which would otherwise escape and carry heat with it. It is best to use the small burner (if provided on the range) for simmering. The use of triple pans over a single burner saves gas. Do not use a larger quantity of water than is necessary. Shut off the gas a short time before you remove the utensil.

There are many "gas-saving" devices on the market. Some devices of this nature would have been added to the range by the manufacturers if they would make a saving in gas, because that would have been a good selling point for the range. Some of the devices sold increase the gas consumed and others have proved dangerous by interfering with the free circulation of gases.

The new Loraine oven heat regulator. The oven heat regulator is a device which automatically regulates the oven temperature. The

operation of this useful device will be understood by reference to the diagram, Fig. 108. The inlet tube *N* is connected to the gas supply pipe, and the outlet pipe *O* to the oven burner. The copper tube *A* is inside the oven at the top. When wheel *H* is turned to the right, it pushes the lever in so that the gas valve *K* opens wider. More gas flows, and a hotter oven results. One end of the lever rests on the end of the porcelain rod thimble. After the gas has been turned on and the oven gets hot the copper tube *A* expands a great deal while the porcelain rod expands but little. The spring *E* keeps the porcelain rod snug to

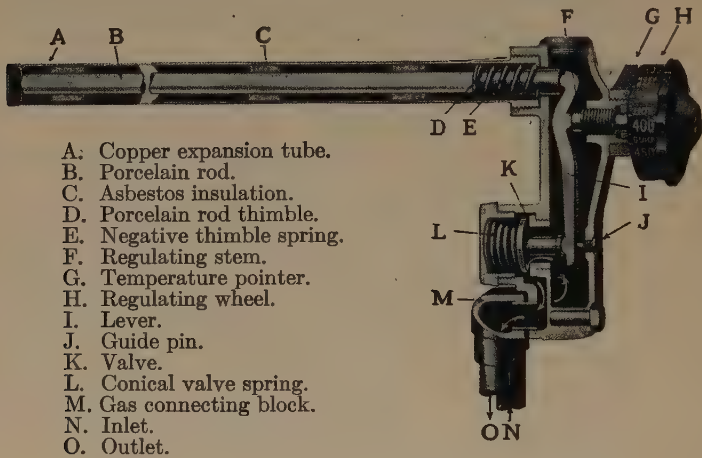


FIG. 108. — The new Loraine oven heat regulator.

the left end of the copper tube. With a rise in temperature, the right-hand end of the porcelain tube moves to the left and allows the top of the lever to move in the same direction. Since the regulating stem *F* acts as the fulcrum of the lever, the lower end of the lever moves to the right and the spring *L* closes, or partly closes, the gas valve, and so shuts off or reduces the flow of gas. As the oven cools, the copper tube contracts, and the gas valve is opened. A pilot flame in the oven lights the gas when it comes on. By adjusting the regulating stem by turning the regulating wheel a temperature can be maintained automatically within narrow limits.

The gas oven. The burners on the gas oven are also of the Bunsen type, and their adjustment is based on the same principle as the top burners. In lighting the oven burners, be sure to open the oven door before applying a flame to the gas, lest an explosive gas mixture in the oven cause damage. A small pilot light is usually provided, by means of which the oven burner is lighted when the burner valve is open. The

oven requires a large supply of gas. The products of combustion — water vapor and carbon dioxide — if allowed to escape into the room, are objectionable. Sweating of the walls and windows results, and the oxygen value of the air is reduced. Some of these objectionable features are absent when a stovepipe is provided to carry the products of combustion to the chimney flue. It is well to have a damper in the stovepipe to regulate the draft when the burners are turned low, and to shut off the draft when the oven is not in use. It is desirable, also, to have a hood over the stove, with an opening to the flue at the top, to carry off the water vapor and odors which come from cooking food. The rusting of the oven indicates a faulty draft, which fails to carry off the water vapor. If the oven becomes rusty, the iron should be cleaned by rubbing with a stiff brush. It should then be warmed and tallow should be rubbed upon it.

The ordinary gas oven is very wasteful of heat. The walls are not insulated and give out about as much heat into the room as is used in the oven itself. The best ranges are now made with insulating material surrounding the oven, saving from 25 to 50 per cent in gas and in the time required to get the oven to the baking temperature.

The electric range. The electric range of today does not look very different from the gas range. There is no fuel to burn, no gaseous products to escape into the room. At a turn of a switch the heat starts. There are the heating plates for use with kettles and saucepans, a broiler, and an oven for baking. The oven is well insulated so that heat is conserved. The heating element for the hot plate is enclosed and is not harmed when food boils over on it. The electric range has an automatic oven heat control, and can have a time switch which will turn the current on and off at any set time. More about the electric range will be found in Chapter XVI. There are many small electric devices such as the electric casserole, sandwich toaster, electric roaster, and grill.

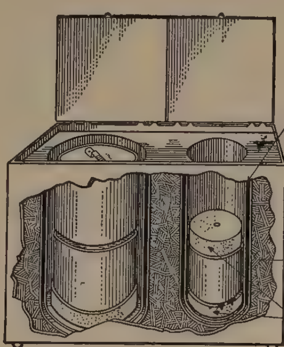


Fig. 109. — A fireless cooker.

Principle of the fireless cooker. Since the cooking of most foods consists merely in keeping them at a temperature of approximately 180° F. to 212° F. for a certain time, it is not always necessary to have a fire during the entire cooking process. If a food, warmed to 212° over a fire, is removed from the fire, it will continue to cook until it has cooled

20 to 40 degrees. By surrounding a hot body with a good heat insulator, which does not permit convection currents, the time during which a high temperature can be maintained is lengthened. A fireless cooker is a device employing heat-insulating materials to prevent the loss of heat from the food and thus continue the cooking without the use of fire.

Most fireless cookers found on the market are lined with aluminum or zinc. The inside packing is asbestos, mineral wool, magnesia, or some other non-conducting material. Cooking utensils to fit the various compartments, racks for holding pies, and radiators form the equipment. The radiators are usually cast iron or soapstone. The soapstone is porous and breaks more easily than the iron, and the iron rusts badly. Either, however, when placed in the cooker, will maintain a higher cooking temperature than is possible without it. If above 250°, the lowest "sizzing" temperature, the radiators cause excessive evaporation of water when foods are cooked in water. The covers of the cooker compartments sometimes have valves which permit the escape of steam.

Advantage of the fireless cooker. In addition to the advantages of the fireless cooker arising from its maintenance of an even cooking temperature without watching, and a cool kitchen in hot weather, it effects a great saving of fuel. The usual processes of cooking are extremely wasteful because only a small part of the heat produced is utilized for cooking. With the fireless cooker, fuel need be consumed only a short time to heat the food and the radiators to the cooking temperature; the insulating material of the cooker prevents the escape of heat and maintains this temperature.

SUMMARY

1. Foods are cooked by boiling, broiling, frying, and baking.
2. The ranges, by their construction, make it possible to utilize the heat of burning coal, oil, or gas advantageously in cooking by all four of the above processes.
3. The Bunsen burner permits the admission of air and its mixture with the gas before burning, so that a clean, hot flame results.
4. The gas range has two sets of burners, both of the Bunsen type. These are: top burners over which are placed dishes containing foods to be cooked; and the oven burners for baking. It is always desirable to have the products of combustion carried to the chimney, but it is much more important to do this if natural gas is used than if manufactured gas is used. Gas oven temperatures can be regulated automatically by having certain attachments made to the range.

5. By a special type of burner, kerosene is vaporized. It gives a non-luminous flame which is used in the kerosene range for cooking, including baking.

6. Most cooking can be accomplished at a temperature between 180° and 212° F., though in baking and roasting the temperature may go as high as 500° for the surface layers of the food.

7. The fireless cooker is a device in which a hot food retains its temperature, through heat insulation, until it is cooked. The most common use of the fireless cooker is for foods that are usually cooked in boiling water, but it bakes satisfactorily if heated radiators are added.

8. The fireless cooker saves fuel, makes it unnecessary to heat the kitchen in hot weather, and improves the texture and flavor of many cooked foods.

9. The fireless-cooker principle of insulating walls is applied to gas-heated and electrically heated ovens, with a saving in the cost of heating.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Development of cooking devices.
2. Relative merits of the steam cooker, pressure cooker and fireless cooker.
3. A study of flames.
4. Care of the top burners of a gas range.

CHAPTER X

SMALL HEATERS AND HOT-WATER SUPPLY

Convenience of small heaters. There is scarcely a home that does not contain a portable heating device, taking gas, gasoline, or kerosene, for fuel, or using electricity. Besides being useful in summer for cooking and the laundry, these portable stoves are convenient in cold weather for warming the house. The oil and gas stoves will quickly warm the bathroom, or take the chill from the dining room in the morning. In early fall and late spring, the small heater gives all the heat desired. In severe winter weather, when the house heater is taxed to its utmost, these small heaters give useful auxiliary heat in the rooms where it is most needed. They may also be used to prevent pipes from freezing, or to save vegetables and fruits in the cold closet. The popularity of these stoves is due to their convenience and efficiency. Heat may be obtained at a moment's notice; the heat is applied where it is needed; and energy is consumed only while it is being used.

The electric heater. When cleanliness, ease of operation, and hygienic results are the only things to be considered, the electric heater stands first. The electrical energy, in passing through a suitable resistance, is changed to heat, and also produces a pleasant, glowing light. The heating element radiates heat in all directions. That which goes to the back is reflected so that it joins that radiated to the front, and a strong radiant heat is given in front of the heater. In many localities the cost of electricity makes this heater too expensive for common use; but in others where electrical energy is cheap, or where a special low rate is allowed for heating purposes, the device holds well-deserved popularity.

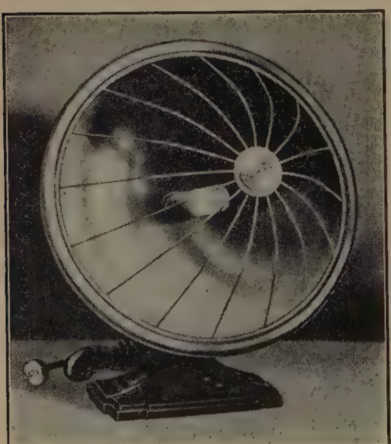


FIG. 110. — A radiant electric heater.

Radiant gas heaters. Of the various types of gas heaters the radiant is the most popular and at the same time very efficient. Its glow of light suggesting the fireplace light adds a bit of cheer. The gas burner

is of the Bunsen type giving a non-luminous flame. The gas is distributed through many small openings, and the flame is directed upon the radiants, which are made of fire clay. These radiants are heated until they glow; they send out intense radiant heat. It is better to have a hood and pipe connected to a flue to remove the products of combustion, but many heaters are used without them.

Fig. 111. — A radiant gas heater.

Dangers from flueless gas heaters. When gas burns with an ample supply of oxygen, carbon dioxide and water vapor are produced. If these escape into the room, some discomfort, but no serious harm, is likely to result. With a limited supply of oxygen, incomplete combustion follows, and carbon monoxide is produced. Carbon monoxide is an odorless gas, so deadly poisonous that air containing 0.1 per cent will cause fatal results in a very short time. Improperly adjusted gas heaters may give off carbon monoxide.

Moisture from burning gas. An important reason for removing the products of burning gas is to prevent condensation of moisture on the walls and windows. The amount of " sweating " produced in this way, of course, depends upon the quantity of gas burned. The moisture, when not removed through a flue, does damage not only to the woodwork and paper or paint on the wall but also to any iron materials, as flatirons, knives, tools, and cooking utensils, through the rust that is caused. The quantity of water resulting from burning gas is indicated in Table XIV.

TABLE XIV

Combustion of Gas

	Requires	Yields	
		Carbon Dioxide	Steam
1 cubic foot natural gas	10 cubic feet of air	1 cubic foot	2 cubic feet
1 cubic foot manufactured gas	5 cubic feet of air	½ cubic foot	1 cubic foot

The water which comes from the condensation of steam resulting from the combustion of 1000 cubic feet of natural gas has been calculated

to be about $10\frac{1}{2}$ gallons, and from 1000 cubic feet of manufactured gas about 5 gallons. One pint of water in the form of vapor will saturate 5300 cubic feet of air. Suppose that a natural-gas heater consumes 125 cubic feet of gas a day; that quantity of gas will yield $10\frac{1}{2}$ pints of water vapor, or enough to saturate 55,000 cubic feet of dry air. But air is seldom dry. If this air were half saturated at the start, the added moisture would be enough to saturate 111,000 cubic feet, and with less than 55,000 cubic feet of air present some of the moisture would be deposited.

The kerosene heater. The central-draft, wick heater is one of the popular types of portable kerosene heaters. This gives a cheery, luminous flame which can be seen through the gauze or mica window, and is exceedingly efficient in warming a small room. Water can be boiled in a dish set on top of the stove. A damper closes the holes in the top surface when the stove is used to warm the room, but this should be open if it is used to warm anything placed upon it.

The burner is hollow and adapted to a cylindrical wick. The wick can be raised or lowered by turning an adjusting wheel, which turns cogwheels engaging holes in the metal wick carrier. Covering the central opening of the burner is a flame spreader, one shoulder of which just covers the top of the wick. When the wick is turned low, it is completely covered with the metal and no air has access to it. In the vertical wall above the shoulder are many small holes through which air comes to supply oxygen to the inside of the flame. The flame spreader must be kept thoroughly cleaned; the carbon must be kept from the metal which covers the wick; the air holes must be kept open by occasionally cleaning with a stiff brush. The wick tubes need cleaning with fine sandpaper. If the holes in the flame spreader or in the base outside the wick tube are allowed to clog, insufficient air will be secured, and smoking will result. Loose threads from the poorly trimmed wick will sometimes cause smoking. If kept in proper condition, an oil heater should not produce the disagreeable odors which are common with neglected oil heaters.

Fig. 112. — Kerosene heater.

Watch the oil dial and never allow the reservoir to go dry, because burning of the wick will follow. Under proper use, about one-fourth of an inch of the wick is exposed. From this the oil vaporizes and is

burned. There should be little or no burning of the wick itself. This burner is not to be compared in efficiency with the circulation oil heater which has a jacket to promote circulation of air by convection currents. These heaters have a storage oil tank, and the burners are of the type found in the oil ranges. They are, however, mostly used as permanent heaters.

FIG. 113. — Circulating oil heater.

The blast torch. A blast lamp using kerosene, alcohol, or gasoline is frequently found in the home. It is particularly useful in soldering and in many other ways, for the man who is mechanically inclined. All these lamps operate on the principle of the plumber's torch. Air is pumped into the reservoir, from which the liquid fuel is forced by this air pressure. The outlet is through a very small jet at the end of a metal tube. The metal tube is so placed that, when the flame is started, the tube will be kept hot and the fuel inside vaporized, so that only a gas issues from the jet outlet. To start the torch, fuel must be burned in a small cup under this tube to heat it sufficiently to vaporize the liquid.

The camp stove. For the camping auto tourist, a gasoline stove is ready for almost instant service. This stove may have one or several

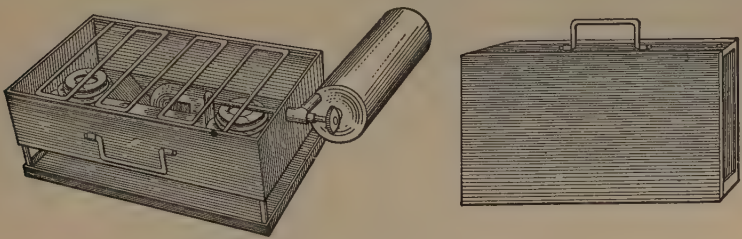


FIG. 114. — A gasoline stove for camp use.

burners, shielded from the wind for outdoor use. At one end of the stove is the gasoline reservoir with a small air pump attached. The gasoline is delivered under pressure to the burners, where it is vaporized.

The principle of operation is the same as that of the blast torch, but the burners are of different form so that vessels for cooking may be set upon grates over the fire. In all burners of this type the liquid or the vapor fuel is delivered through a very fine orifice, which must be kept free from obstruction. It is, therefore, necessary to have perfectly clean fuel put into the reservoir. If the orifice becomes clogged with dust, fine sand, or other matter, it is usually possible to clear the opening with a fine wire or priming pin. Stoves of this type are also made for burning kerosene.

Hot-water supply. A convenience which has become almost a household necessity is a constant supply of hot water to various parts of the building. A supply of hot water in sufficient quantity for household purposes, and ready for instant use upon opening the faucet, is easily secured. The most common way to heat this water is in a water pipe which is placed inside the lining of the firebox of the coal range. It is sometimes heated by a coil of pipe which passes into the furnace. For summer, and for houses which have no coal stove in the kitchen, the gas heater serves well. For country houses where no gas is available, a similar heater, burning kerosene instead of gas, gives satisfaction. A large galvanized-iron or copper storage tank is needed to hold enough water for the regular washing, for the bath, and other household purposes.

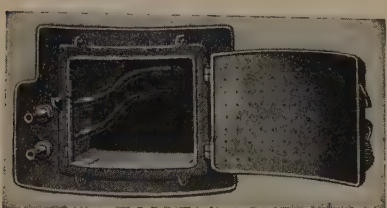


FIG. 115. — Furnace attachment for hot-water supply.

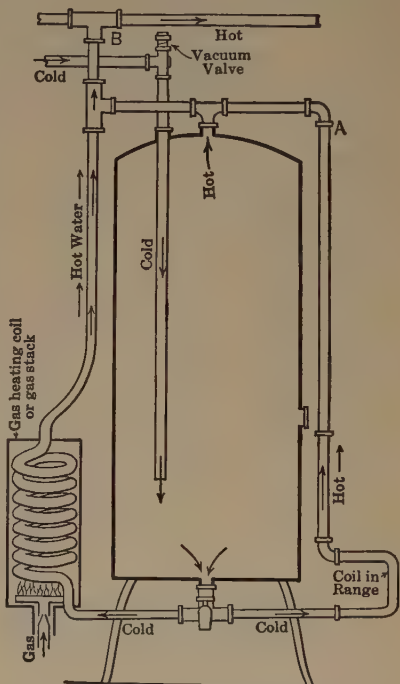


FIG. 116. — Hot-water supply tank, with range and gas coil connections.

Hot-water supply system explained. A pipe leading from the bottom of the tank connects with the water front of the coal range. After making a circuit in this, it goes back to the tank, passing either through

the side of the tank about halfway to the top or connecting with the pipe entering the tank at the top as shown at A in Fig. 116. With a gas heater, the hot water goes from the heater directly to the pipe at the top of the tank B. When gas is used, we frequently want a small amount of hot water, but we want it at once, and hot water is delivered to the faucet without passing through the tank.

When hot water is drawn from a faucet, a supply of cold water enters from the supply pipe, which passes through the top of the tank and extends down to a level just above the top of the heating device. It is unsafe to have the supply pipe extend lower than this, else the water might be drained from the heating coil or water front in the range. If these pipes were drained without extinguishing the fire, the pipes might get red hot and then, if water were admitted, the sudden production of steam would result in a serious explosion. Sometimes a tank, usually placed in the attic, supplies water directly to the hot-water tank. This supply, or expansion, tank receives water from the supply pipe and is automatically regulated by a floating ball-valve control.

The vacuum valve. If a bad leak in the cold-water service pipe should occur when all the hot-water faucets were closed, the water in the tank might be siphoned out and produce a vacuum in the tank. If the leak was in the basement and the tank on the second or third floor the vacuum could easily be so great that the outside atmospheric pressure would cause the ordinary tank to collapse. In order to protect the tank from this danger a vacuum valve may be installed on the inlet pipe at the top of the tank. This is a one-way valve. When the pressure inside the pipe is reduced it opens and allows air to enter.

PROBLEMS

1. Apply the principle of convection, and explain the movement of water in the system when the fire is warming the water in the water front of the stove and all the faucets are closed.
2. Explain the movement of water in the system when the hot-water faucet is opened.

Care of the hot-water supply system. Water should be drawn from the faucet under the tank, from time to time, to remove the sediment. The water front of the range must never be drained when there is a fire in the stove, else it may crack or even cause a serious explosion. Coils of pipe running through the stove or furnace need attention occasionally if the water is hard. Deposits of calcium carbonate make heating slower and may even cause stoppage. If water gets boiling hot, and bubbling or rumbling is heard, open a hot-water faucet; this lets cold

water into the tank and prevents the generation of steam, which otherwise might produce enough pressure to strain the joints. It also might force the water from the water front and allow it to become overheated; then when the pressure was relieved and water entered the overheated water front, the sudden formation of steam might result in an explosion.

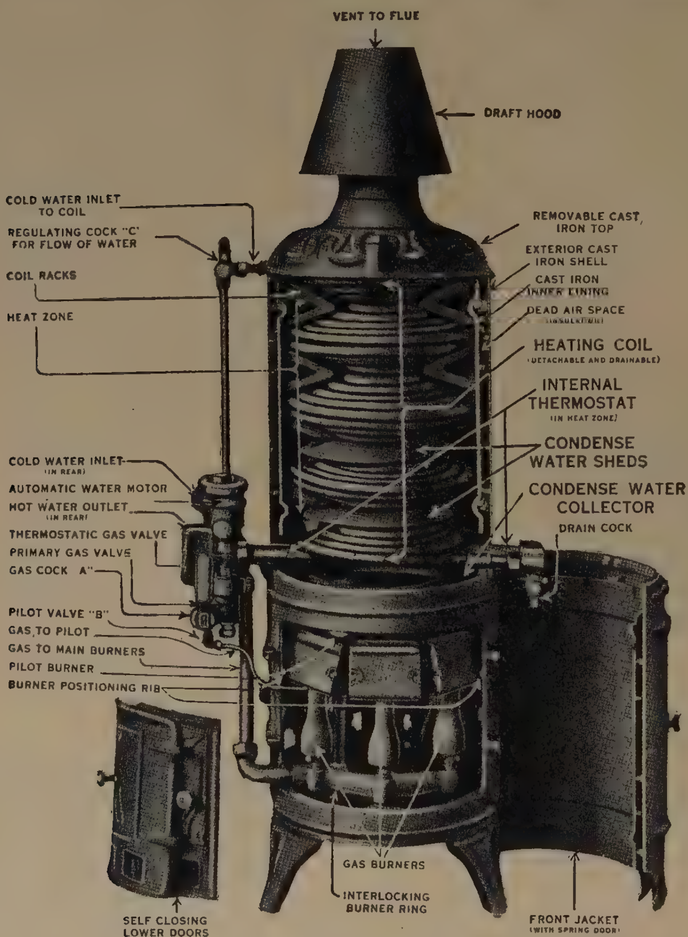


FIG. 117.—An automatic gas water-heater. Continuous-flow type with no storage tank.

Automatic gas water-heaters. There are two general types of automatic gas water-heaters; the *continuous flow* and the *storage*. The continuous-flow type (popularly known as the *instantaneous* water-heater) has no storage tank, but, when the water is turned on, it automatically turns on the gas to warm the water, and when it is turned off,

the gas is turned off too. A small pilot light, which is burning all the time, serves to light the gas when it is turned on. Practically no gas is burned except when the faucet is open. There is a very long coiled pipe through which the water flows; in this, the water is heated hot as fast as it passes through. With such a heater no tank is needed. It is generally advantageous, especially for a rapid flow of water, to have a storage tank. In the storage tank the gas is burned at a much slower rate, but for longer periods of time. The gas is automatically cut off when the tank is filled with hot water, and turned on again when cold water enters. The thermostat can be set to keep the water at any desired temperature. Much gas is saved by having the tank well insulated.

Hot water from the house heating unit. A stack for a hot-water supply that is gaining favor is one that can be attached to the hot-water or steam boiler which is automatically fired. This gives a

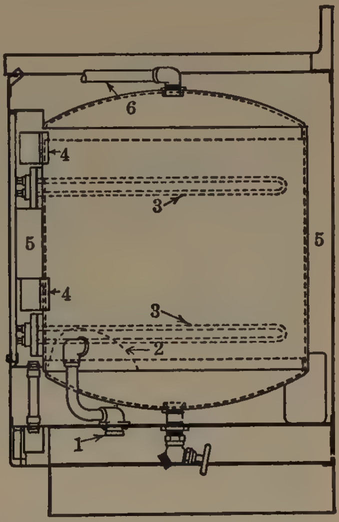


Fig. 118.—Electric water-heater. Section at right. (1) Cold-water inlet. (2) Baffle. (3) Calrod heating elements. (4) Thermostats. (5) Rock-wool insulation. (6) Hot-water outlet.

supply of hot water the year round. The stack has a coiled pipe through which the water for the hot-water supply passes. Hot water from the boiler circulates through the stack around the coil. In the summer no heat goes to the rooms. By means of an aquastat placed in the boiler, the water temperature is kept down below boiling so that no steam is produced in the steam heater and the flow valves to radiators in a hot-water system are closed. The use of the heater with its small amount of heat helps to dry out cellars with a tendency to dampness.

Electric water-heater. Electric water-heaters may be of the storage type (see Fig. 118), where many gallons may be heated and kept in readiness for use, or they may be of the continuous type which heats the water only when it flows from the faucet. In both types, loss of heat is carefully guarded against by insulation. The heating element is a coiled nichrome wire inside a metal sheath known as Calrod or Corox. The heat passes through the sheath outside of the core to the water. A thermostat automatically controls the current and maintains an even temperature of water. One kind of thermostat used in the storage type of electric water-heater has a compound metal disc which is larger than the one used in the electric iron, but which works on the same principle.

Another electric water-heater is of the immersion type. A metal cylinder has the heating element inside. There is an insulated handle through which the electric cord passes. The metal cylinder is immersed in the liquid to be heated. This type is used for heating only a small quantity of liquid.

FIG. 119.— A water-heating garbage burner.

Water-heating garbage burner. Various types of incinerators are available for burning garbage for the home. When the garbage is considerable in amount, as in an apartment house, not only does burning provide a satisfactory method of its disposal but the heat produced may be utilized for heating water. The illustration (Fig. 119) shows one type. A small coal fire is maintained on the lower grate. The garbage is placed above and dries out. After drying it is burned. The heat warms water which passes through the pipes and is stored in tanks as in the regular hot-water supply system.

Freezing of hot-water pipes. It is a very common occurrence for hot-water pipes to burst in cold weather when cold-water pipes are unharmed. This is not due to any difference in the freezing temperatures of the two, but rather to several other reasons. The cold water has not been heated and so contains air dissolved in it. Upon freezing the air separates and, because it can be compressed, serves as a cushion to take up the expansive force of the freezing water. On the other hand,

water that has been heated has lost its dissolved air, and so the full force of the expansion due to the formation of ice is directed against the pipes. Hot-water pipes are commonly made of brass or copper, whereas, until recent years, cold-water pipes have been made of iron. Brass and copper are better conductors of heat than iron and so cool faster. Iron is stronger than brass and copper, and consequently resists pressure of expanding ice with more force.

When water begins to freeze in the pipe, its pressure in the enclosed space is increased. An increase in pressure lowers the freezing temperature; therefore water will not burst a pipe unless its temperature is considerably below 32° F. Thawing frozen water pipes with lamps, torches, or any bare flame is a serious fire hazard. Frequently a pipe can be cleared by the application of boiling water or hot cloths. By

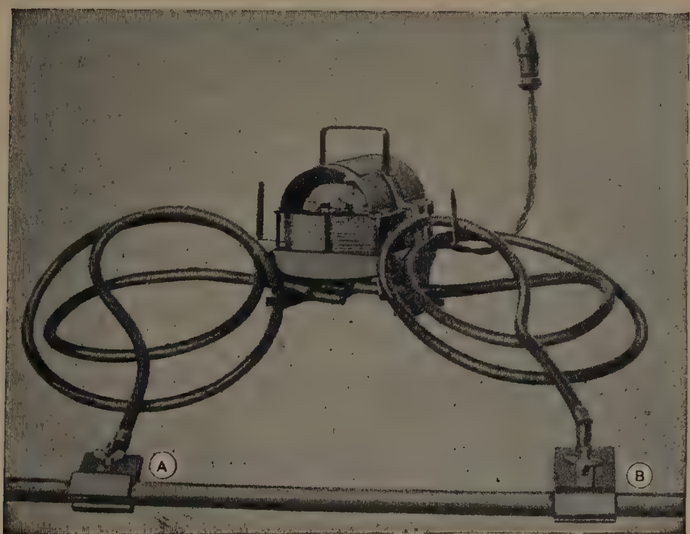


Fig. 120. — Device for thawing pipes by means of electricity.

means of an electric thawing device, Fig. 120, the pipe can be thawed quickly and without danger from fire. The device is a step-down transformer (see page 229) which lowers the voltage taken from the lighting circuit but steps up the heat-producing current. It consumes about the same amount of electrical energy as an electric iron. A faucet is opened, and the clamps from the secondary coil are placed on the pipe a short distance apart. The electric current passes through the pipe between *A* and *B* in which the water is frozen. The pipe is heated in sections until the water runs, which usually occurs in a very short time.

SUMMARY

1. Small heaters furnish an important service in the home; in cool weather and on cold mornings. They remove the chill from the room, and in severe cold weather they provide auxiliary heat to help the larger heaters.

2. Disregarding the possible expense of operation, the electric heater offers more advantages than any other small heating device.

3. Radiant gas heaters are popular and give satisfactory service. With any gas heater care must be taken to see that the combustion is complete, else the deadly poisonous carbon monoxide will be set free. It is better to carry the products of burning out of the room by means of a flue connection.

4. A large amount of water vapor results from burning gas. If there is no flue connection, this will condense on windows, walls, and various objects in the room, often doing much damage.

5. One of the most popular small heaters burns kerosene. It has a central draft and works like a huge central-draft lamp. When kept clean and trimmed, this stove is economical and gives excellent service.

6. There are many devices of the blast-torch type, burning kerosene, gasoline, or alcohol. They all have a fuel reservoir into which air may be pumped to provide pressure for forcing the liquid fuel out. The fuel is vaporized so that a gas flame is produced. The gasoline camp cooker is of this type.

7. In one type of hot-water supply, a storage tank is connected by pipes to a heating coil situated in the range or furnace, or in a separate unit for gas or kerosene heating. The heating coil should never be drained unless the fire is extinguished, for, if it is, the coil will get so hot that, when water comes into it again, steam may be generated under sufficient pressure to cause an explosion.

8. Automatic, instantaneous water-heaters do not require a storage tank. Opening the faucet automatically turns on the gas flame, and closing the faucet shuts off the gas. The water is heated as it flows through the pipe in the heater.

9. Electricity is much used as a source of heat for hot water. It keeps the tank full of hot water automatically.

10. Heat derived from combustion of garbage may be a source of heat for a hot-water supply.

11. In cold weather the hot-water pipes are more often frozen than the cold-water pipes because, in freezing, the cold water liberates air which serves as a compressible cushion. Brass pipes cool more quickly and are less strong than iron pipes.

12. Frozen water pipes may sometimes be thawed by applying hot water with cloths. Underground pipes are best thawed by means of a strong electric current.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Small heaters as fire hazards.
2. Merits of different types of heaters for hot-water supply.
3. Compare the humidity of the air in a room before and after using a small heater for two hours.
4. Compare the relative costs and efficiencies of a kerosene, a gas, and an electric portable stove.

CHAPTER XI

HOUSE HEATING

Modern house heating has progressed by the aid of science in keeping with the changes in other departments of life. While cars have become streamlined, furnaces have new " trim lines " and are smartly enameled. They may be colored to harmonize with the decoration of the recreation room.

The one greatest change in home heating systems within recent years is the automatic control. No longer is it necessary to shovel coal, carry wood, or clean out ashes. Today fuel is fed to the furnace automatically, and an even temperature in the house is maintained without any thought or effort of man. There are automatic stokers which feed fine coal to the fire, and automatic pumps send oil to burners. In some sections natural gas is the common fuel. Even manufactured gas is burned in furnaces for house heating. In a few places where electrical energy is very cheap, electricity is used. It is the ideal way to heat because of its cleanliness and because it needs no machinery, not even a chimney to carry off gases. The heating device may be joined to or combined with an air-conditioning unit.

Heat exchange between a person and objects in the room. We have already referred, in Chapter VI, to the exchange of heat between bodies of different temperatures and to the resulting loss of heat by the warmer body. Let us now consider the application of this principle to a person entering a furnished room. If the room is unheated and a person enters it on a cold winter day, he soon feels cold. The air and objects in the room are very much colder than the person. Whenever two bodies are touching or are near each other, there is an interchange of heat energy, the warmer always losing to the colder. Heat from the person's body passes through his clothing by conduction and air movement. Heat is also radiated to the walls and to objects in the room. The walls and objects, being at a lower temperature, cannot radiate as much heat to the person as they receive from him. Hence the objects are warmed slightly, while the person cools off. The warmer the walls, the greater the amount of heat radiated to the person, and the less taken from him. Since a person is generating heat all the time, he should lose more than he receives. The proper balance is obtained at about 68° F. to 72° F. for an inactive person, but at a lower temperature for one

doing vigorous, muscular work. An elderly person requires a higher room temperature than a younger one.

Minor sources of heat. In addition to the heat persons give to a room from their bodies, direct sunlight is an agent of considerable importance. It helps warm our houses in winter, if we let it in, and it gives too much heat in summer unless we shut it out. Not only does the light change to heat when it is absorbed by matter in our rooms, but with the rays of light are mixed the rays of heat, which have their origin in the sun. Proper arrangement of the shutters makes a marked difference in the comfort of rooms on the sunny side of the house.

What it means to heat a room. One British thermal unit will warm 1 cubic foot of air 55° F. One pound of coal yields 12,000 B.t.u. It seems, at first thought, that a house might be warmed by burning a few pounds of coal. The problem of heating is not quite so simple, however. Much heat is lost through the chimney. Moreover, it is not merely the air which must be heated, but the floor, walls, woodwork, and furnishings. The air of the room takes but a small portion of the heat required. The amount of heat absorbed by the various materials in the room, in being warmed, depends upon their specific heat. Brick and air take about the same amount of heat, weight for weight, but pine wood will absorb twice as much heat as either brick or air in being warmed through the same change in temperature. It takes 20 per cent more heat to warm oak wood than to warm pine. Metals take less heat than wood or stone.

A single door to a room or a single piece of furniture may absorb more heat in being warmed from 40° to 70° than is required to warm all the air in the room through the same range of temperature. Many times, when a room is being warmed, the thermometer surrounded by air and protected from loss by radiation will record 70°, but we feel chilly. The walls of the room are not yet warmed to 70°, and we radiate an excessive amount of heat to them.

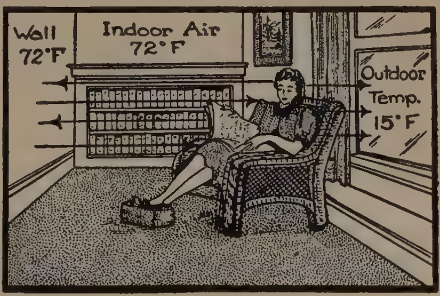


FIG. 121.—Why does one sometimes feel uncomfortably cool on the side of the body toward a window?

Suppose that you are comfortable in a room in which both air and walls are at 70° F. If the walls are poorly constructed so that the wall temperature drops to 67° F. then the air temperature must be raised to

73° F. to give you the same comfort. If the walls drops to 60° F. then the air must be warmed to 80° F. Insulation of all exposed walls, double windows, and double outside doors are effective means of maintaining an even, comfortable temperature throughout the rooms and also effect a saving in fuel. Persons and objects in a room lose more heat by radiation through windows than by radiation to walls. The purpose of a heating system is to supply enough heat so that a person will not cool off too much. The heat is not to warm a person but to check his cooling off.

Advantages of double windows. The use of double windows may reduce the fuel bill as much as 20 per cent in some buildings. The con-

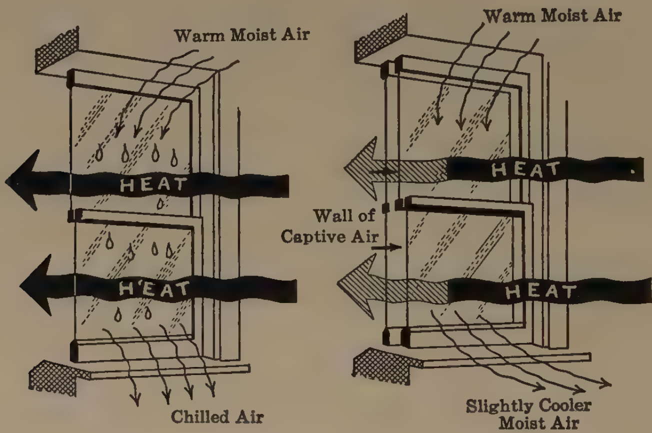


FIG. 122.— Much heat is lost when moisture condenses on a single window in cold weather. The resulting dry air also feels cooler because of increased evaporation.

fined air between the two glass surfaces is an insulation. The inside glass does not become so cold as it would without this insulation. This higher temperature results in several advantages. It prevents loss of much heat. It prevents the formation of frost on the glass and so preserves the visibility of outside objects. Prevention of condensation on the glass is also a heat saver because, when a gram of water vapor is condensed, it loses 537 calories of heat, much of which would be taken by the air out of doors. The humidity indoors can be kept at a high level without frosting the windows of a double glass.

How a room loses heat. Heat is lost from a room in a variety of ways. There is some conduction and radiation of heat through the glass of windows. There is some conduction through the walls. Much warm air leaks through cracks around doors and windows or up the flue, if

such a ventilation device is provided. It is possible that air may circulate to some extent through plaster and brick walls. How porous a brick is may be determined by weighing it dry and then reweighing after it has been soaked in water for several hours. The increase in weight represents the weight of water in the pores of the brick. Air may easily be forced through a brick.

The house-heating load. The fuel needs for house heating are determined by the temperature of the atmosphere. As long as the minimum temperature during the day does not fall below 60° F., no artificial heat for warming the house is required; but when it does go below 60° F., heat must be supplied in order to make the house comfortably warm.

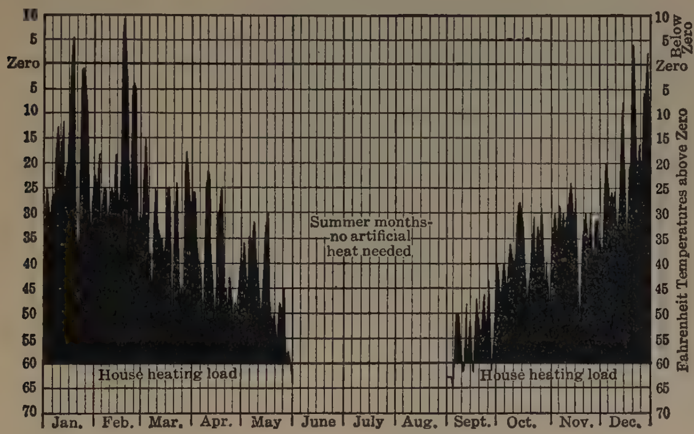


Fig. 123. — The house-heating load.

The wide variations in daily and seasonal temperatures produce corresponding variations in heating needs. A study of a typical minimum temperature record for a year, Fig. 123, discloses the fluctuating demand made upon our heating systems. The " house-heating " load is represented by the black areas in the figure. The greatest range results during the lowest temperature; this may be called the " peak load." The house-heating equipment must be of a capacity to take care of the peak load, though you will readily see from the chart that it will not be used to its full capacity very much of the time.

Modern fireplaces. The fireplaces in our modern houses are seldom built with the idea that they will give ample heat to the room, but rather that they may provide auxiliary heating in extremely cold weather, or as the only source of heat in mild weather. Quite as often, however, the fireplace is desirable for the cheerfulness and coziness which it always spreads among any group gathered about it. The air

in the room is not warmed much by a fire in a fireplace, but objects, walls, etc., are warmed by radiation. Since the air is not overheated, as it often is in other systems of heating, it retains more nearly its outdoor humidity. This gives us a more agreeable feeling. An-

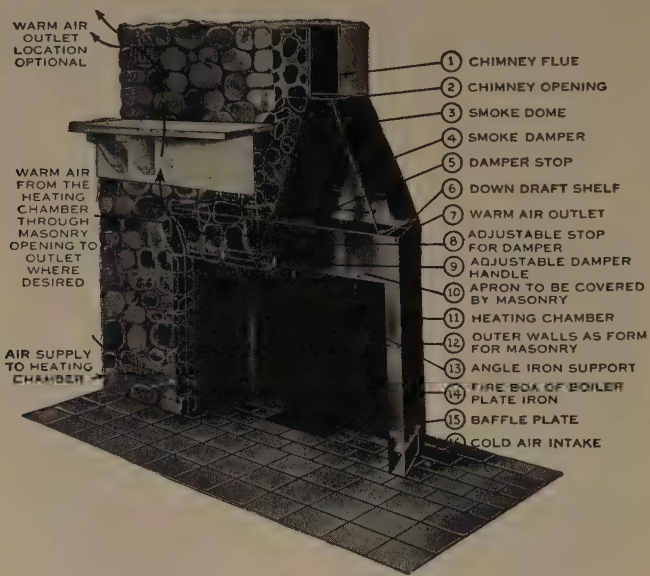


Fig. 124. — How to utilize more of the heat of a fireplace.

other advantage of the fireplace is that foul air is carried up the chimney. In fact, a large amount of air not needed in combustion of the fuel passes up the chimney. This means a large loss in heat. The ordinary type of fireplace is not an economical heating device; only about 10 per cent to 20 per cent of the heat of the fuel is effective in warming the room in the best fireplaces. This, and the fact that the room cannot be heated uniformly, are the chief reasons why fireplaces are not relied upon for practical heating. Many attempts have been made to improve the efficiency of the fireplace. One of the most successful methods is to surround the fire space with metal ducts. These ducts have openings near the floor, and at some distance above the top of the fireplace they have outlets from the wall. Air enters the bottom openings, circulates round the fire chamber, absorbs a large amount of heat, and is discharged into the room from the top openings.

Stoves. Stoves in the house serve two purposes: heating and cooking. The construction of the stove depends upon its purpose and also upon the kind of fuel which is to be burned in it. Certain essential

features, however, are common to all stoves. The ordinary kitchen coal range was shown on page 117. A coal stove for heating purposes is shown in Fig. 125. Coal is burned on a *grate,* below which is the *ash pit.* In the door of the ash pit is a slide, covering or opening holes in the door. This is the *draft.* The stove is joined to the chimney by a stovepipe, in which is a *damper.* When either the damper or draft is closed, the circulation of air through the fuel is reduced and the fire is checked. *A check draft* is placed in the door through which the fuel enters the fire chamber, and frequently a second check draft is place in the stovepipe. Except for

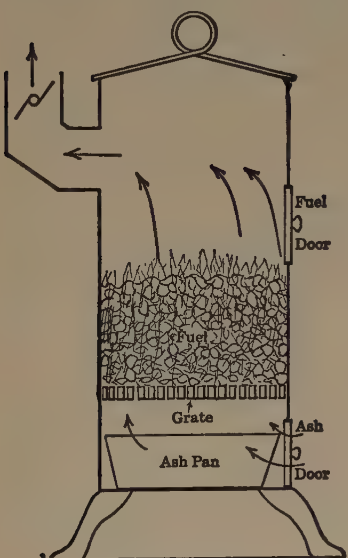


FIG. 125.—A stove.

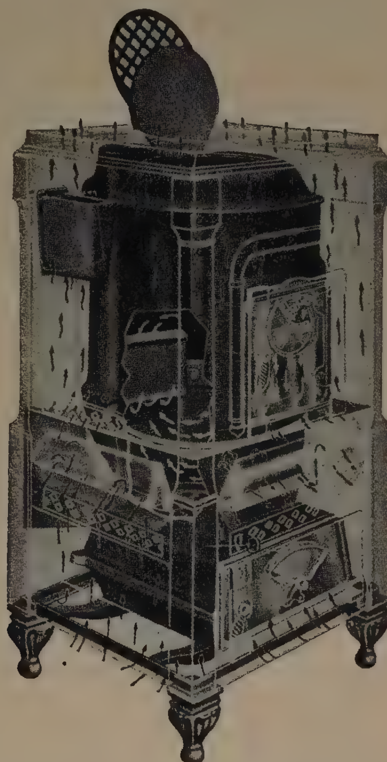


FIG. 126.—One type of jacketed stove for producing a more even distribution of heat throughout the room.

a short time after new fuel has been added, air allowed to enter the fire chamber *above the fuel* checks burning, as it reduces the air which passes *through the fuel.*

To secure the hottest fire, open both the damper and draft and close the check draft. For some time after fresh coal is put on, not enough air may be supplied for complete combustion. Carbon monoxide, a poisonous gas, will then be produced. The damper should, therefore, always be left open for a time after adding fresh coal, to allow the carbon monoxide to pass off. If the fresh coal does not cover all the live coal,

the live coal will generally set fire to the gas set free from the fresh coal and the carbon monoxide will be burned up.

A room heated by a stove is uncomfortably warm near the stove because of its intense radiation but may be uncomfortably cool at a distance. A much more even distribution of heat is produced by having a metal jacket around the stove with a free air space within. This reduces the radiation of heat outside the jacket and by increased convection carries more heat to distant parts of the room.

How a room is warmed. Our modern stoves are far more efficient than fireplaces, as they utilize 70 per cent to 80 per cent of the heat of the fuel. Air in contact with the hot surface becomes heated, expands, loses in density, and is pushed up by denser air which comes in to replace it. The air in these warm currents is cooled by windows, the cold walls, and colder air with which it mixes, and at length it sinks to the floor, moves along the floor to the stove, and finally pushes the warmer air upward, thus completing the convection circuit. Radiation also plays an important part in warming a room. The air absorbs but little of the radiated heat, but the furniture and walls receive much of their heat from this source.

The amount of heat a body receives by radiation depends upon its nearness to the stove, for the intensity of radiation varies inversely as the square of the distance. To illustrate, suppose that a surface of 1 square foot is 2 feet away from the stove and that it is then moved to a position 4 feet away from the stove. The distance has been doubled, and the radiant heat received will be but $\frac{1}{2 \times 2}$ or $\frac{1}{4}$ as much as when it was 2 feet away. Multiply the distance by 3, and the heat will be only $\frac{1}{9}$ as great. What would be the heat received if the distance were made 4 times as great?

Cast-iron stoves with rough surfaces radiate more heat than smooth, sheet-iron stoves. Heat is brought through the metal, from the inside to the outside surface, by conduction.

The warm-air furnace. The warm-air furnace is in reality a large heater much like a stove, surrounded by a metal jacket from which ducts lead to the rooms to be heated. In order to establish natural convection currents, the furnace must be lower than the rooms, and consequently we find the furnace, as a rule, in the cellar. The surface of the combustion chamber must be large, to warm the large volume of air which passes between the walls of the heater and the outside covering, on its way through the ducts to the rooms. The operation of the furnace is practically the same as that of the stove. A check draft is commonly combined with the damper in the smokepipe. This is so arranged that

when the damper is closed the draft is opened, thus admitting air from the cellar to the smokepipe without its passing through the combustion chamber. The other fire and air controls will readily be understood by a study of Fig. 127.

Source of the air supply. It is important that the air heated and sent to the rooms be pure. Outdoor air is best. A cold-air flue is built to conduct this air from a cellar window to the furnace. The window which supplies this air should be on the windward side of the house, but where no pollution of the air is likely to take place. Preferably,

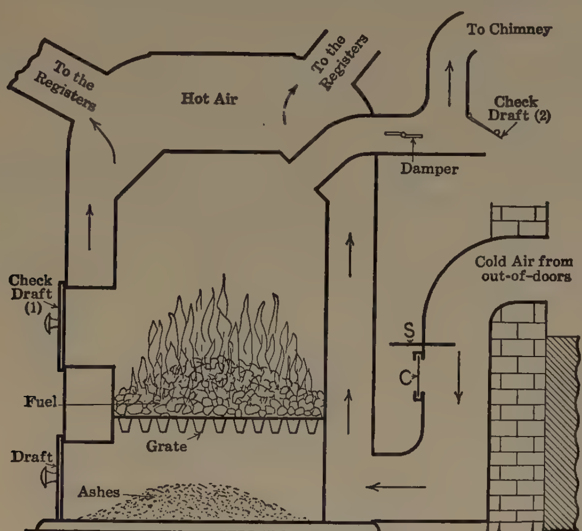


FIG. 127.—A warm-air furnace.

this air inlet should be several feet above the ground and protected from rain, snow, and dust. It should be well screened; a coarse cloth may be used in addition, to filter the air.

Regulation of the air supply. When the air is heated it expands. This increase in volume varies with the temperature. Four cubic feet of air from out of doors in extremely cold weather will give just as large a volume of air in the rooms as 5 cubic feet in mild weather. Hence, less cold air should be admitted in very cold weather. In the cold-air flue there is a slide to regulate the volume of air which enters from out of doors. During very cold weather, outdoor air has a high density, and so naturally the air in the convection currents moves faster than at other times. If too much cold air is admitted to the furnace, it is not warmed sufficiently unless the fire is increased. Much coal is wasted by neglecting the regulation of the cold-air flue.

"Burned" air. For another reason, care must be taken in the regulation of the air admitted. If too little air is admitted, so that the air is not moved quickly out of the heating chamber, it will become overheated and result in air which is very uncomfortable because of its "burned" condition. Organic matter and dust in the air are burned, and the products together with the excessively dry air irritates the membranes of the air passages.

Reheating the air. When few people are using the rooms, it is not necessary to draw an entirely new supply of air from out of doors. The cool air from the rooms or possibly from the cellar is suitable. If the heating system provides for reheating the air from the rooms, the registers for the cold-air ducts should be placed near windows and near the

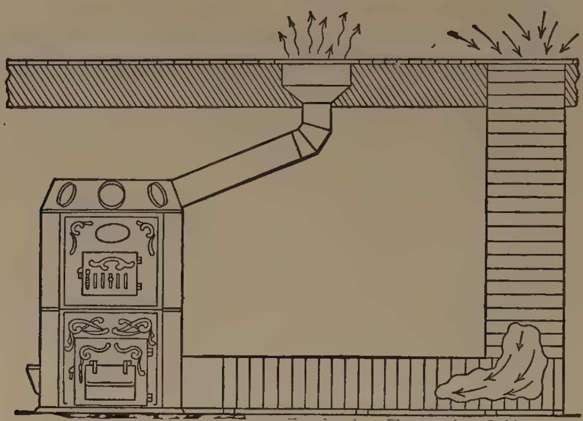


FIG. 128. — Recirculated air system.

bottom of a flight of stairs, if there is an open stairway with upper and lower halls. If this is done, the cold air which comes in around the windows and down the stairway will be taken directly to the furnace to be warmed.

One-pipe and three-pipe furnaces. The *one-pipe* or *pipeless furnace*, Fig. 129, is a warm-air recirculation type of heater. It delivers warm air through one large register so placed that it will easily warm the principal rooms of the house. Other rooms opening off these will be warmed by the circulating air currents. Upstairs rooms may be warmed by having registers which allow warm air from the rooms below to rise into the rooms, or by convection currents by way of an open stairway. Cold air is returned to the furnace through a register which surrounds the warm-air register. Outside the heater is the chamber for warming the air, and outside of this air-warming chamber is another chamber through which the downward currents of cold air

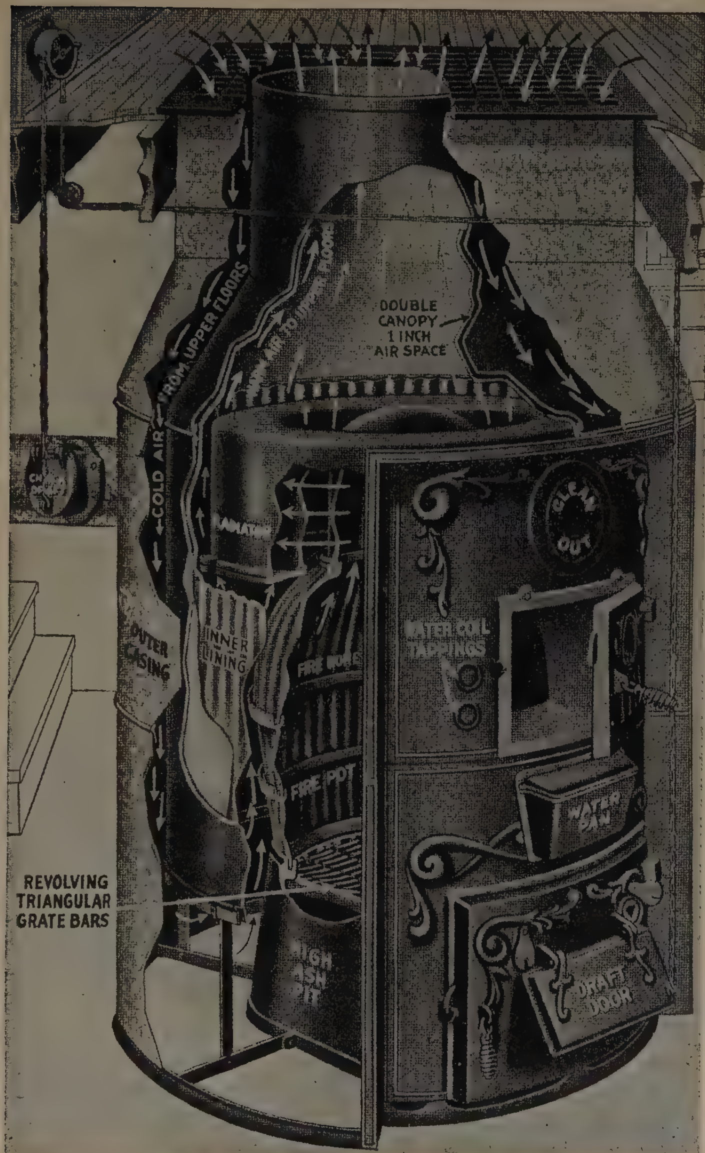


Fig. 129. — The one-pipe warm-air furnace.

flow. Little heat is lost to the cellar because the cold air absorbs practically all the heat which is carried to the outside wall of the heating chamber.

The heating of distant rooms will be improved by having return ducts to bring cold air from them direct to the furnace. A furnace having two return cold-air ducts and one central warm-air duct is called a *three-pipe furnace*. It is like the one-pipe furnace in all respects except the manner of returning the cold air.

A furnace humidifier. The water tank, usually set into the base of the air chamber of the warm-air furnace, is practically useless. The water in this tank does not get hot enough to vaporize quickly; and even if the tank is kept filled with water, which it rarely is, it cannot give an

Fig. 130. — A constant supply of water to humidify the air as it leaves the furnace can be secured by means of this humidifier.

adequate supply of vapor to raise the humidity to the proper degree. An improved form of humidifier has an evaporator placed at the top of the heater, with an outside automatic water control. This consists of a small tank connected to the water-supply pipe. The entrance of water is controlled by a valve operated by a ball float. The level of water in this tank maintains the same water level in the evaporator in the furnace.

A fan in warm-air heating. A fan in a domestic warm-air heating system will often counteract defective installation, such as too long leader pipes, too small warm-air ducts, too small cold-air return pipe, and wrong location of the furnace. It is quite common for furnace castings to reach above 600° F. in gravity circulation, but they may be kept at 300° F. in a fan circulation system. Air from the register may be 175° F. in the gravity but only 140° F. in the fan system. It is much more desirable to have a large volume of the cooler air than a small volume of hot air. Tests have shown a fuel saving of 15 to 30 per cent by means of a fan.

If one wishes to use filter screens to remove the dust from the air, to wash the air, and to spray it to increase the humidity, this can be done

much better in a fan-driven current of air than in air moved only by gravity.

We are coming to the point where we may wish to have fan-circulated air in order that we may install a cooling unit in the cold-air duct and circulate cool air throughout the house during hot days of summer.

Hot-water heating. In a hot-water heating system, water is heated in a boiler in the cellar. Connecting pipes carry the hot water to the radiators in the rooms and bring the cooled water back to the boiler. An expansion tank is located in the attic. The entire system is full of water.

Convection currents. Heat is transferred from the boiler to the radiators by convection. The water in the boiler is always below the boiling temperature, ranging from 100°–120° F. in mild weather to 175°–185° F. in cold weather. The water is about 10 degrees colder when it leaves the radiator than when it enters. This difference in temperature is so small that there is very little difference between the density of the water in the *flow pipe* (that going to the radiator) and the density of the water in the *return pipe* (that returning from the radiator to the boiler). It is this difference in the weight of these two columns of water, however, that furnishes the force to move the water through the system. This difference is not likely to be more than one- or two-tenths of a pound in any part of the system. The higher the radiator is above the boiler, the greater the difference in the pressures of the two columns of water; consequently, the movement of water through the radiators on the second and third floors will be more rapid than through those on the first floor. This inequality of flow may be corrected by having the pipes going to the upper floors smaller.

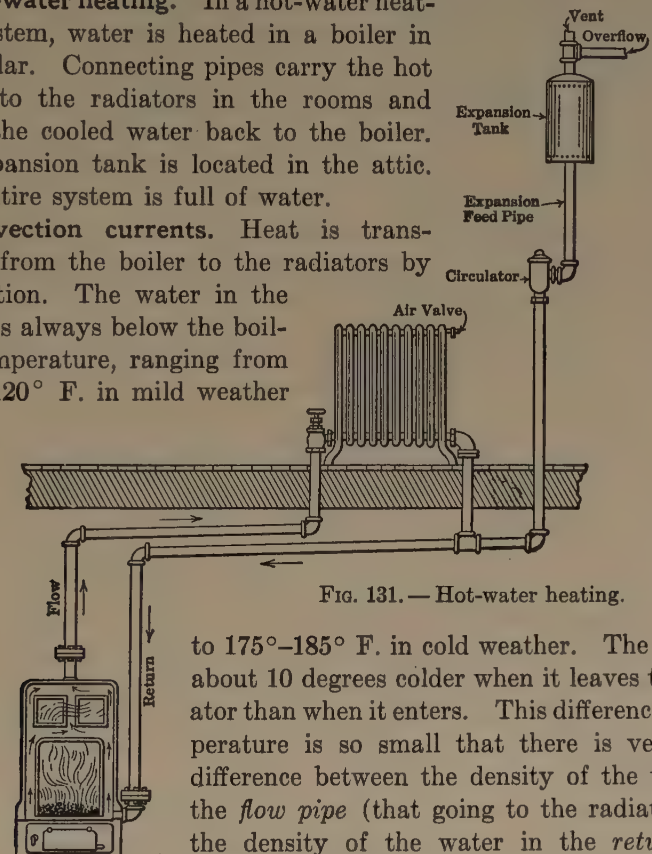


FIG. 131. — Hot-water heating.

How the room is warmed. The heat which the water absorbs from the burning fuel is carried by conduction through the metal radiator to the air. The air carries the heat by means of convection currents to all parts of the room. Considerable heat is radiated directly to the walls and to objects in the room. The room is heated more by convection than by radiation, however, and this, together with the moderate temperature of the radiator, insures a more even heat distribution throughout the room than is given by a stove or by steam radiators. Radiators coated with aluminum or bronze paints containing flakes of the metal deliver only 80 per cent as much heat to the room as they do when painted with zinc oxide, white lead, or enamel paints. The color used is not an important factor in heat dissipation.

Pressure in the boiler. The pressure in the common hot-water boiler is due entirely to the height of the water column reaching to the highest part of the system. In a four-story building, this would be about 20 pounds per square inch. The regular cast-iron boilers are not used for buildings over three stories high. In taller buildings, the boilers must be made of wrought iron to stand the pressure.

The expansion tank. Since hot water occupies more space than cold water, if cold water, enclosed in any system of pipes, boiler, and radiators, were heated, the resulting pressure would cause a rupture in some weak spot in the system. To prevent this, a tank, located at a higher elevation than any of the radiators, and connected to the return pipe of the boiler, receives the overflow when the water expands. If contraction results from cooling the water, the tank supplies water to keep the system filled. To make up for leakage or other loss, the supply in this tank is increased from the city supply pipe which is opened and closed automatically by a ball-float valve, which maintains a constant water level in the tank all the time. An emergency overflow leads from this tank to the roof or to the sewer.

A cool sleeping room. One drawback to hot-water heating is that we desire a cold room for sleeping. In mild weather we shut off the radiator part way; this allows a very slow movement of water through the radiators, and does not waste much heat. But should the temperature suddenly go very low, the water might freeze, either in the radiator or in the connecting pipes in the walls of the buildings. It is not safe to shut the radiator off entirely, because of the danger of freezing. The radiator may be left on full with the windows wide open; this will usually give us a cool room, but it is very wasteful of coal. The entire water supply of the heating system will be so cooled that the drafts will need to be opened earlier in the morning to warm the house properly. An effective way of meeting this difficulty is to leave

the radiator on full all night, but to prevent loss of heat by wrapping a heavy bed comforter closely about the radiator. This preserves the heat, keeps the water in constant circulation, and removes the danger of freezing.

Automatic damper control. Many hot-water boilers are equipped with an automatic device for keeping the water within a narrow range of temperature. As shown in Fig. 132, a mixture of alcohol and water is nearly surrounded by the hot water of the boiler. At 200° F., enough alcohol is vaporized to exert sufficient pressure to lift the weight on the lever arm, and thus to close the draft and open the check draft. When the water has cooled a few degrees, the pressure is decreased and the weight falls, opening the draft and closing the check.

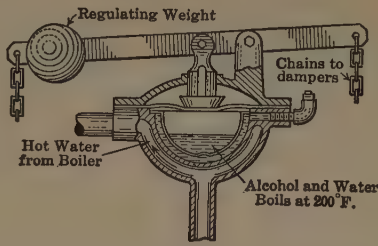


Fig. 132. — Automatic draft control for this hot water heater.

Steam heating system. A steam heating plant is, in its main features, like the hot-water system. It has no need, however, of an expansion tank, and the construction of the boiler differs in minor details. The boiler is never filled with water, but a certain space is left for steam; the water level can be seen through a glass gauge.

Principles of steam heating. The principle upon which the heating of a room depends is practically the same, whether we consider a steam radiator, a hot-water radiator, or a stove; but the transference of heat from the boiler to the radiator differs radically in steam from that in hot-water heating. In hot-water heating the hot water gives up its heat to the radiator *during the process of cooling.* In steam heating, the *steam gives off its latent heat as it condenses* in the radiator. The resulting water leaves the radiator at practically the same temperature as that of the steam entering. The temperature of the steam radiator is usually about 212° F., but, if the steam is delivered at 5 pounds pressure, its temperature is 227° F. About half the heat given to the room by the radiator is transferred by convection and the other half by radiation.

Care of the boiler. In order to get as near the full value of the heat as possible, the dust and ashes should be cleaned out of the various cavities of the boiler, where they collect. This dirt is a poor conductor of heat, and when it is left on the surface of the boiler, a hotter fire is required to produce steam. There are several small doors on the boiler marked " Clean out," and some cleaning can also be done from the large door of the firebox.

The water in the boiler should be kept clean. Very dirty water will froth on boiling, and will then tend to boil over and thus carry sediment into pipes, which may thus be partly closed and so interfere with the circulation. It is well, occasionally, to draw off some of the water from the boiler. If it is muddy or full of sediment, let the fire go out and draw off all the water. Wash out with more water, then fill.

One of the most common boiler accidents is fracture of some of the sections, and one of the most common causes of fracture is low water. The common practice of burning old papers and rubbish in the furnace of the boiler, in the summer, is a bad one. The heat thus produced is very intense and of short duration. The water is at the usual steam level; this keeps the lower part of the boiler cool, while the part above the water line gets extremely hot. The difference in temperature of the two parts causes severe expansion strains which often result in fracture. If the boiler is to be used as an incinerator in summer, fill it completely with water to prevent unequal heating and expansion.

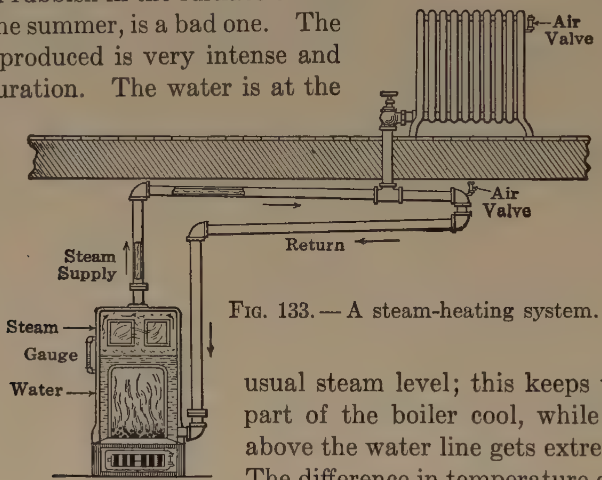


Fig. 133. — A steam-heating system.

When building a new fire in a cast-iron boiler, *always make a slow fire,* in order that the expansion of the parts may be gradual. All the radiators and pipes are cold at first, and more than a normal amount of water resulting from condensation will, for a time, be removed from the boiler. If the radiators are cold at night, condensation will draw water from the boiler when it is started in the morning. There is always danger when the water level falls from sight in the gauge glass. If the water in the glass drops out of sight, water must be added slowly until it is visible again. When the return water comes back, it should not rise in the glass out of sight; if it does, some water must be drawn off. If the water cannot be maintained at a level within the limits of the gauge glass without addition and withdrawal, the boiler is too small for the number of radiators.

Water hammer. When steam suddenly comes into contact with cold water or cold radiators, it condenses, and a vacuum results. If there is water in the pipes with steam pressure behind it, it may move through the vacuum with great speed and strike a hard blow against the iron pipe. A series of blows due to the sudden rushing of water into a vacuum and its striking against the pipe, or other water, results in the pounding, snapping, or rattling in steam pipes, known as *water hammer*. The remedy is to warm up a cold system gradually, or to prevent the collection of cold water in the pipes by suitably placed drip pipes.

Pressure gauge. A pressure gauge is attached to the boiler to show the steam pressure in the boiler and radiators. In moderate weather, the gauge may not indicate any pressure, but in cold weather it will be necessary to run with several pounds pressure and to keep the radiators filled with steam.

The operation of the gauge depends upon the action of a curved metallic tube, Fig. 134, closed at one end but with the other end open to the boiler. Through this open end, steam communicates pressure to the inside of the tube. Since the tube is curved, the area of the outer wall surface is greater than that of the inner wall; consequently, this wall has more pressure exerted upon it and the pipe tends to straighten. The greater the steam pressure in the tube, the greater the movement of the closed end of the tube. The closed end of the tube, which is free to move, communicates motion by action of a lever and cogs to a pointer, which indicates the pressure on a dial. The dial figures signify pressure in excess of atmospheric.

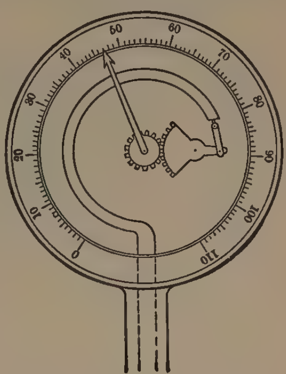


FIG. 134. — Pressure gauge.

Radiator air valves. When the steam is first sent into the radiators, the air must be pushed out through the air valves. These valves permit air to pass in either direction when the radiator is cold, but when hot, they are closed, thus preventing steam from escaping. They are automatic in their action. The expansion of a metal pin, when the steam reaches it, closes the opening. People sometimes open these valves to let the air out faster in order to warm the radiator quicker. This is bad practice because it is a delicate matter to get the valves accurately adjusted again. If not perfectly adjusted, they will either prevent the entrance of steam into the radiator or permit the escape of steam and overflow of water into the room.

Vapor-vacuum and vacuum-pressure systems. In the usual steam heating system, steam, in order to enter the radiator, must overcome the atmospheric pressure to push the air from the radiator. Every time the radiator cools down, air enters and must be pushed out before the radiator can be warmed again. This takes time and requires greater pressure and a higher temperature in the boiler than would be needed if no air were in the system. In a vacuum system, when steam is first produced it forces the air from the system. All the air escapes from the air valve, which is in the basement. There are no air valves on the radiators. When the steam reaches the controller or air valve after all the air has been ejected, the controller is closed by the expansion of a brass tube. In some systems the air is exhausted by means of pumps, and only a low temperature is needed to fill the radiators with steam at the very start. When all atmospheric pressure is removed from a system, the water will boil at 98° F., and with one-half of the pressure removed it boils at 180° F. The term **vapor-vacuum heating** is commonly applied to those systems which deliver steam to the radiators at or below 212° F. In a **vacuum-pressure system,** a vacuum is maintained in the return pipe and steam under pressure in the flow pipe. This is always a two-pipe system, and the joints must be absolutely air tight.

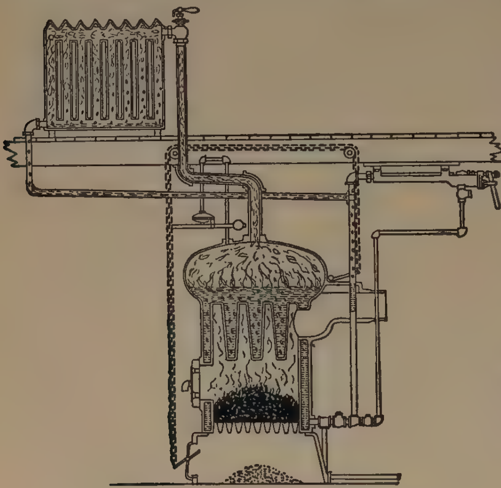


Fig. 135. — The vapor-vacuum system.

Advantages of the vacuum system. In this system of heating there is no spitting of water or hissing of steam, both so common with the steam radiator valve. The inlet valve is usually at the top of the radiator and may be opened full by a single turn of the handle. It may be opened part way and the amount of heat regulated to suit the weather conditions.

The vacuum system provides an agreeable heat, much like that from the hot-water system, though it is more expensive to install. It is more economical in its fuel consumption than either steam or hot-water heating.

Heat derived from steam. In a steam heating system, the heat transferred from the boiler to the radiator is stored in the steam in a latent condition. The amount of latent heat which is thus carried varies, though not in a very important degree, with the pressure in the boiler. The temperature varies, too, with the pressure. Table XV shows how the properties of steam vary under different pressures.

TABLE XV

PROPERTIES OF STEAM UNDER DIFFERENT PRESSURES

Vacuum	Temperature	Latent Heat
— 10 lb.	160° F.	1003 B.t.u.
— 5 "	181° F.	988 "
— 4 "	197° F.	977 "
— 1 "	205° F.	971 "
Pressure		
0 lb. (Atmospheric pressure)	212° F.	966 B.t.u.
2 "	219° F.	961 "
5 "	227° F.	955 "
10 "	239° F.	946 "

It will be observed that the latent heat is greater when water is vaporized at the lower temperatures, and at the lower pressures. One pound of steam under 5 pounds pressure, in condensing, gives out to the radiators 955 B.t.u.; but 1 pound of steam under 5 pounds of vacuum gives out 988 B.t.u. Under —5 pounds (vacuum of 5 pounds less than atmospheric pressure) the radiator is at 181° F., or about the temperature of the hot-water radiator; but under 5 pounds pressure the radiator is 46° hotter than this. The volume of steam at the lower temperature is greater than at the higher temperature; therefore, in a vacuum system larger radiators are needed than in a pressure system. In the vapor-vacuum system there is less loss of heat by radiation from the boiler and flow pipes, because they are at a lower temperature. The water will boil at 160° F. at —10 pounds or at 181° F. at —5 pounds. Consequently the vacuum system will effect a saving of fuel.

Concealed radiators. The usual type of radiator is frequently unsightly, needs refinishing from time to time, and takes up valuable space in the room. Concealed radiators are popular because they are out of the way and out of sight. They are usually placed in a recess in the wall with an opening at the floor and a grate opening in the wall, just above the top of the radiator. Cool air goes in the opening near the floor, and warm air comes out above. Convection keeps the air in the room in motion.

TABLE XVI

ADVANTAGES AND DISADVANTAGES OF HEATING SYSTEMS

Kind of Heating	Advantages	Disadvantages
Fireplace	Aids ventilation. Low cost. Takes no space.	Low efficiency. (20%.) Uneven heating.
Stove	Low cost. Efficient heating. (70 to 80%.)	Takes much room. Requires much care. Makes dirt and dust. A great fire hazard.
Hot-air furnace	Low cost to install. Aids ventilation. Easy to operate. Temperature changes quickly. No radiators in room.	Large consumption of fuel. Brings dust into rooms. Danger from coal gas. Irregular heating.
Hot water	Small consumption of coal. No dust. Easy to operate. Even temperature.	High cost of installation. No ventilation provided. Danger from freezing. Temperature changes slowly. Radiator space large. Unsuited to tall buildings.
Steam	Small consumption of coal. No dust. Distant rooms easily heated.	High cost of installation. No ventilation. Temperature changes slowly. Radiators take room. Sometimes noisy.
Vapor	Small consumption of fuel. No dust. Temperature changes fairly quickly. All rooms easily heated.	High cost of installation. No ventilation. Radiators take space.

The Minneapolis thermostat. In the Minneapolis thermostat, a curved strip of metal is fastened at one end and has a long arm extending downward. The lower end of the suspended arm plays back and forth between two set screws. Expansion due to warming causes the coil to open, and the arm touches the right-hand screw. Upon cooling, the coil contracts and the arm touches the left-hand screw. Whenever the arm touches one of the screws it completes an electric circuit which mechanically operates the heat-controlling device. A clock attachment to the thermostat makes it possible to have the heat automatically turned on at an early hour in the morning before you arise.

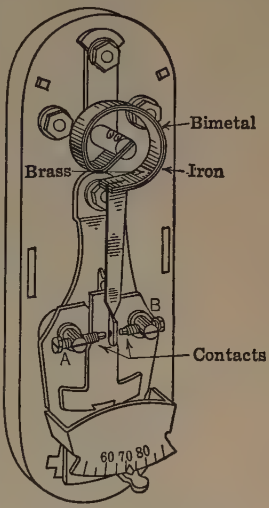


FIG. 136. — Bimetal thermostat.

There is an interval of time after the thermostat has turned the heat on before the room temperature actually changes; also there is a lag in time after the heat is shut off before the temperature stops rising. This causes an undesirable fluctuation in room temperature. This defect is decreased in the new-type thermostat which has a small electric heater built into the thermostat. When the room temperature starts to rise, an electric current adds a small amount of heat to the bimetal plate. The added heat hastens the action of the bimetal and decreases the time period between the " on " and " off " action. By this means, the room temperature is kept more uniform.

Oil burners. Oil as a fuel for any type of heater has many advantages over coal, coke, or wood. Except for the necessity of keeping the oil tank filled, the oil heating system is entirely automatic. There is no labor or dirt. Any desired temperature may be secured by setting the thermostat. The principle on which the many different makes of oil burners operate is to break up the oil into extremely fine particles in a process called atomizing, and to mix the atomized oil with air so that it burns just as a gas would. There is one important difference between the oil-burning and coal-burning heater. The coal may be burned very slowly and it keeps some heat all the time, whereas the oil burns strongly when it is on, but, when it is off, no heat is produced. Oil is pumped to the burner under pressure. It may be spread by means of a centrifugal pump, or thrown by the atomizer principle of a strong air current over the open end of a tube. Some type of blowing fan driven by an electric motor forces a steady stream of air to mix with the oil

which is burned in the firebox of the heater. Either gas or electricity may serve to ignite the mixture when the burner starts action. The electric ignition is more expensive to install, but costs less to operate.

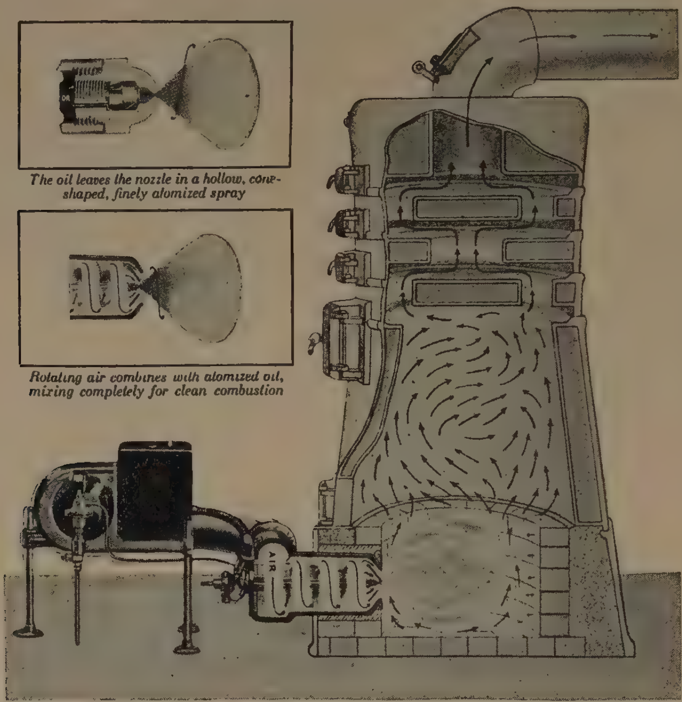


Fig. 137.—Oil burner combining rotating air with atomized oil.

Gas heating. Where natural gas is plentiful and cheap, there is no better way of heating the house than to burn it as a fuel. It has the advantages of oil heating and, in addition, no thought need be given to renewing the supply. The fuel is always ready. Manufactured gas is also suitable, with slight modification of the burner, but, in most localities, manufactured gas is rather expensive in comparison with oil. In Fig. 138 the steam regulator (1) or, in hot-water heating, the water regulator, controls the supply of gas. This acts automatically at a predetermined steam or water pressure. The motor (2) is connected to the throttling valve by which it shuts off the supply of gas when the desired temperature in the rooms has been reached. It is operated by a thermostat control. The gas pressure governor (3) keeps the gas pressure at a fixed amount. The gas passes through the supply line (4) to the supply valve (5), which controls the gas to all the burners.

The burner (6) has raised drill ports, giving a blue flame which is silent. A thermostat pilot shuts off the gas and keeps it off if the pilot should be extinguished. Thick cellular asbestos insulation (8)

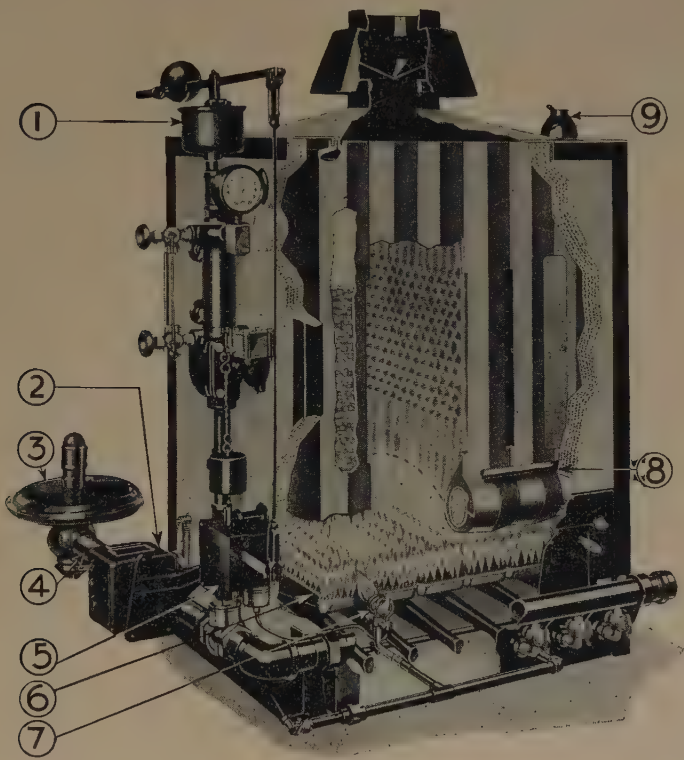


FIG. 138. — A gas-heated furnace.

is commonly applied to prevent loss of heat from gas heaters. A pop safety valve (9) insures safety from any possible overheating of the boiler.

SUMMARY

1. When a cold room is heated, it is not the air alone, but also the walls and the objects in the room, that absorb the heat.

2. A room loses heat by leakage of warm air, by conduction through walls, and by radiation through windows.

3. Fireplaces give us pleasure and comfort but are extravagant consumers of fuel.

4. Coal stoves and furnaces have a draft to admit air beneath the coal, a check draft above the level of the coal in the fire chamber, a damper and a check draft in the smokepipe. By proper adjustment of these the fire is controlled.

5. The furnace warms the rooms by convection currents. Stoves warm them by convection and radiation.

6. The warm-air furnace does the work of several stoves. From some central location in the cellar, it sends warm air through metal ducts to the different rooms to be heated, by means of convection.

7. It is important to regulate the air which is to be heated in the warm-air furnace. If too much is admitted it will be too cold; if too little, it will be "burned." Air may be returned from the rooms for reheating, but in general it is better to take fresh outdoor air.

8. The warm-air furnace is more convenient than stoves, but not quite so efficient. It gives satisfaction in small houses. Friction in the ducts prevents warm air from flowing to rooms which are distant but not much higher than the furnace.

9. The humidity may be increased by evaporating water at the top of the heater. A constant supply of water must be provided.

10. In hot-water heating, heat is carried from the boiler to the radiators by convection water currents. The room is warmed chiefly by convection air currents, but to some extent by radiation from the radiators.

11. The expansion tank receives the excess of water during expansion and keeps the system full of water when contraction occurs because of cooling or leakage.

12. Hot-water heating gives an even heat, is efficient, and requires little attention. The system is expensive and it cannot be used for tall buildings.

13. In steam heating, heat is stored in steam in the boiler and liberated in the radiator when the steam condenses. The radiators are much hotter than in the hot-water system.

14. In a one-pipe system, water returns to the boiler from the radiator through the same pipe that delivers the steam. In the two-pipe system, one pipe delivers the steam and another returns the water to the boiler.

15. Steam heating is the best for large, and particularly for tall, buildings. It is much warmer near the radiators than at a distance from them, because, being hotter than hot-water radiators, they radiate more heat.

16. Steam boilers are equipped with a safety valve, pressure gauge, water gauge, and usually with an automatic damper control.

17. A vapor-vacuum heater is a steam heater in which the air is

removed from the system and a vacuum is maintained, at least in the return pipe. In some types the entire system is a partial vacuum, with the result that the water is vaporized in the boiler at a temperature considerably below 212° F. This is an efficient heater and gives a pleasing, even heat.

18. Thermostats keep the room temperature fairly constant. They make use of compound bars which, under a change in temperature, close an electric circuit. The electric current will then act upon the furnace control, the radiator valves, or the dampers in the warm-air ducts.

19. The use of oil or gas for fuel for the heater has increased rapidly in recent years. These fuels relieve one of much care as the operation is automatically controlled by thermostat.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. The heating system of the school building.
2. A plan for improving the heating of my home.
3. Care of the heating plant when not used in summer.
4. A study of a model hot-water heating system.
5. How do house-heating methods vary in different parts of the United States?
6. Types of humidifiers and what is claimed for them.
7. Test a room for air leakage.
8. Build a fire in a range or furnace, and care for it for a day.

CHAPTER XII

PROTECTION AGAINST FIRE

Every October for more than twenty-five years, we have had "Fire Prevention Day." But in recent years this has expanded into "Fire Prevention Week." It is designated annually by presidential proclamation, and it is commonly observed in the schools. The great Chicago fire of 1871 held the record for the most destructive fire for many years but lost this distinction to San Francisco in 1906, when the earthquake started a fire that resulted in a loss of $350,000,000. Fires causing damages of a million dollars or more occur on the average about once a year. However, the bulk of fire losses comes from many

Photographed by International News Photos.

FIG. 139. — After fire has visited a home.

small fires. The yearly loss is about ⅓ to ½ billion dollars in the United States, which has the highest fire loss of any country in the world in proportion to its population.

Causes of fires. Study of the causes of fires has shown that the sources of the largest losses are chiefly seven. They are in the following order (those causing greatest losses being given first): (1) matches and smoking; (2) defective chimneys; (3) stoves, furnaces, boilers, and their pipes; (4) spontaneous combustion; (5) sparks on roofs; (6) petroleum and its products; and (7) misuse of electricity.

In all these seven **sources** of fires there is one predominating **cause.** It is **carelessness.** Matches are left where children can get them to

play with. Unextinguished matches are dropped upon inflammable material; kerosene is used to hasten a wood fire; a hot iron is left " for a moment " to be forgotten until a fire is started. A person who has washed gloves in gasoline in the house without harm has acquired a false sense of security and unfortunately is too often willing to take another chance.

Principles of fire extinguishing. There are three essentials of fire: (1) something which will burn; (2) degree of heat above its kindling temperature; (3) a supply of oxygen. Deprive a fire of any one of these three necessities, and the fire will go out. In large city fires sometimes buildings ahead of the fire are dynamited to remove com-

Photographed by International News Photos.

Fig. 140. — A defective chimney caused this fire.

bustible material. In forest fires small fires under control are used to remove combustible material in the path of the larger fire. Every combustible material has a kindling temperature below which it cannot burn. If a burning material is cooled below its kindling temperature the fire is extinguished. Air is the common source of oxygen for fires. If air can be kept away from a fire the fire must go out. Smothering a camp fire by putting earth or sand on the coals, and covering a burning substance with a wet blanket, are examples of smothering a fire.

Kitchen fire hazards. When wood or coal is the fuel used, slow kindling is hastened by some people by pouring kerosene upon the kindlings. If hot coals are in the stove the kerosene may be changed

to a gas. This gas mixed with air makes a dangerous explosive which may not only wreck the stove but set one's clothing on fire. Wood and coal stoves should have metal or asbestos plates under them and extending a foot in front where ashes are taken out. In an oil range burner, no leakage from pipe or around reservoir must be allowed. If the floor becomes saturated with oil just a spark may start a disastrous fire.

FIG. 141. — Using oil to kindle a fire is dangerous.

The gas range is a source of possible danger. Suppose that a kettle of water is left on a burner which is turned high. You have so much water in the kettle you think that it cannot boil away within an hour. You leave the room. The water soon boils over and extinguishes the flame. The unburned gas continues to flow. Before long the air and gas produce an explosive mixture. The pilot flame on the stove touches it off. Windows, doors, and perhaps walls are blown out by the terrific explosion that results. Possibly the house is set on fire at the same time. A similar dangerous explosive mixture may result from gas leaks.

Lard, oils, and other fats when heated may change to a gas and take fire. Smothering is the best remedy. If hot frying fat catches on fire, do not pour water upon it, for this would merely scatter the burning fat in many directions. Cover the kettle with a metal cover if available and then complete the smothering by additional covering with wet cloths. Alcohol used in shellac, many stain diluents, some polishing liquids and stove polishes must be used with caution because they are volatile and inflammable. Gasoline vapor and air make the explosive that drives our automobiles. Never wash with gasoline in the kitchen. Friction sometimes makes an electric spark that will set the gasoline on fire. Take this precaution. Always have a bucket of water close by, even in outdoor cleaning. If gasoline on the gloves you are wearing while cleaning them takes fire you can dip your hands into the water and prevent a serious and painful injury. However, it is better to pay a little more and get carbon tetrachloride, the safe cleaning fluid, instead of the inflammable gasoline.

Living-room fire hazards. The fireplace is a possible source of undesired fire. Wood, particularly partly dried soft wood, contains moisture in small cavities or cells. Heat vaporizes this and puts the steam under pressure until finally it breaks forth with a loud snapping sound. At the same time the force of this explosion sends live coals flying out of the fireplace. It is never safe to leave a fire in the fireplace without a protecting guard of a fine wire mesh fire screen to prevent sparks getting into the room.

Photographed by International News Photos.

Fig. 142. — Always use a fireplace screen.

Floor lamps, table lamps, the radio, and Christmas lights are attached to wall receptacles by means of electric cords. These cords are subject to wear as they are moved and as objects are moved over them, scraping the surface. When the insulation becomes worn so that the two wires within touch each other an electric spark is produced. This may set fire to any inflammable material close to it. It may blow a fuse and cut off the electricity. It is better to give

Fig. 143. — Fires caused by misuse of flat iron and curling iron.

the cords a periodic examination and to bind worn places with tape before the wires become bare.

The heat from many electric-light bulbs is sufficient to set paper or cloth on fire. Whenever you are decorating for any occasion, never leave any paper touching an electric-light bulb. Allow several inches of space, through which air can circulate, between the lamp bulb and the decorating material.

The waste basket usually contains material that easily takes fire. The heads of some matches retain enough heat to set paper on fire after the flame is extinguished. Cigarette butts thought to be extinguished, but in reality still smoldering, are the source of some fires starting in the waste basket. These fires can be prevented by leaving these fire hazards on ash trays.

Fireproofing cloth. The annual fire loss in the United States is around $350,000,000; about half of this is from private homes. Much of this is due to inflammable fabric too close to fire; live coals pop out from the fireplace upon a rug; towels are hung too near a stovepipe; curtains blow into a gas flame; or an overheated iron is left on cloth. It is a simple process to reduce this fire loss by fireproofing materials that may make a fire hazard.

The following solution will give protection. Dissolve 7 ounces of borax and 3 ounces of boric acid powder in 2 quarts of hot water. Dip the cloth into the solution, wring, and dry. For rugs, spray the solution with garden or insecticide sprayer. Fire will char the material, but the chemicals check burning and prevent spread of the fire. The chemicals melt, give off water, and in this way check combustion. A new fireproofing compound now made commercially is the ammonium salt of sulfamic acid. Fabrics treated with this compound can be dry cleaned without losing their fire-resisting property.

Cellar fire hazards. Many fires start in basement cellars. Cellar fires are generally of the worst type because of more rapid spreading. Fire works upward faster than in any other direction. Keeping the cellar free from accumulation of rubbish goes a long way in fire prevention. Stovepipes, hot-air ducts, and the furnace itself unless well insulated must be at a distance from wood or other combustible material. Ashes when taken from the furnace frequently contain live coals. Ash cans should be made of metal. One should not attempt to thaw out a frozen water pipe with the flame of a blow torch. Many fires have been started in this way. Oily waste or cloths saturated with oil by painters must be kept in metal containers. If left in a heap they may start a fire. The oil (linseed) that painters use will slowly oxidize in air. Oxidation produces heat. Sometimes enough heat is produced to cause the cloths to burst into flame. Oil burner accidents do occur in spite of many precautions. Suppose that oil continues to flow when for some reason the spark or pilot light is not on. If the firebox is hot the oil vaporizes and mixes

FIG. 144. — Defective smoke pipe and trash barrel.

with air. If this comes in contact with a spark an explosion will result. If the furnace is not injured soot will probably be sent all over the house and possibly a fire may result in the cellar.

Photographed by International News Photos.

FIG. 145. — Worn insulation started this fire.

Short circuits. There are many causes of short circuits in the home. Worn insulation allows the bare wires in an extension cord to touch. A child may put some metal object into an electric socket joining the two parts of the circuit. A switch sometimes get out of order and a short circuit results. The wire in a lighting fixture may have been twisted in wiring the fixture so that the insulation is removed enough to let a bare wire touch the metal. The socket of the fixture may then give a current to any conductor that " grounds " it. That is, any conductor connecting this to a wet basement floor, a water pipe, or the metalwork of the heating system may carry enough current to blow a fuse or even be dangerous to a person who happens to be the connecting medium between the faulty fixture and the wet ground or floor.

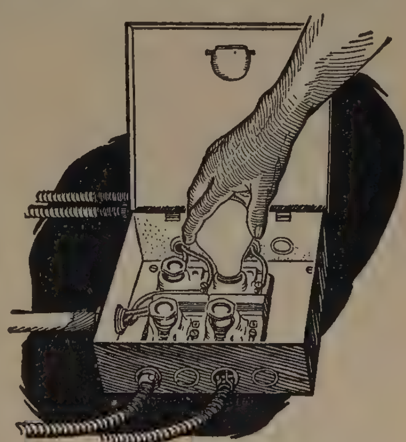


FIG. 146. — A bulb in a fuse socket will remain lighted as long as there is a short circuit, but will go out when the short is removed.

Replace a " blown " fuse in the fuse box by a fuse only of the capacity intended for that circuit. If the circuit is wired for 15 amperes, do not

put in a 30-ampere fuse. To do so is taking the risk of causing a fire at some point within the walls of the building. Never substitute a coin-under-the-fuse for a fuse because this is using no fuse at all. Fuses act as a protection against overheating which may cause fire.

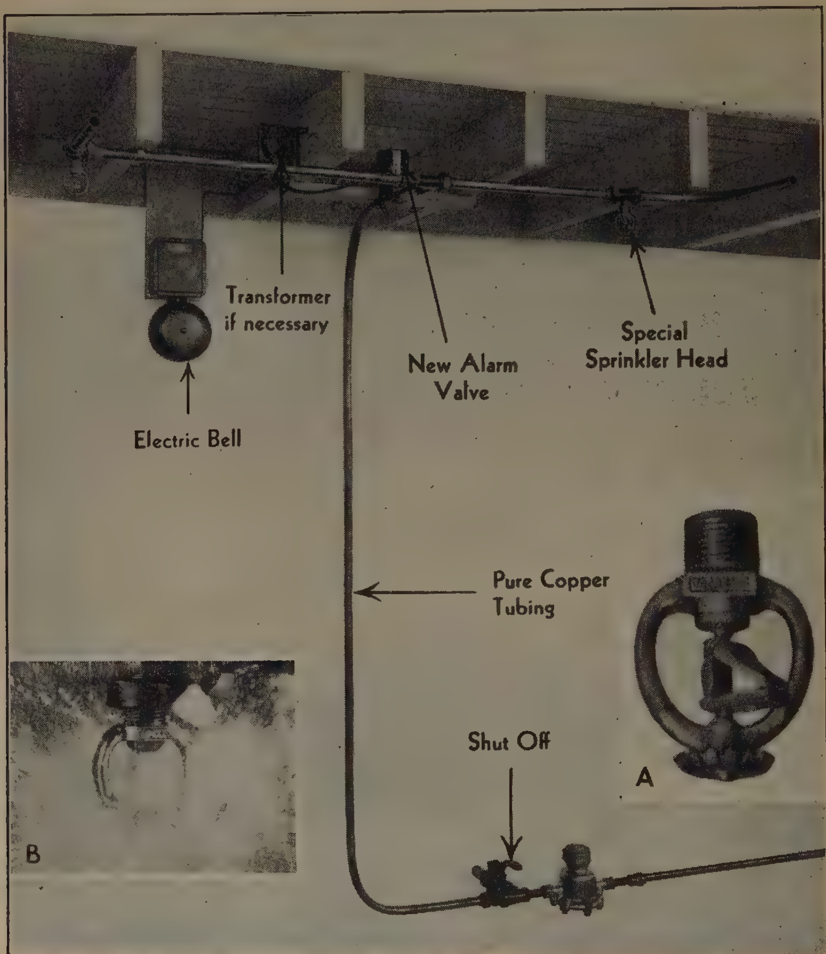


Fig. 147.—Installation of sprinkler system. Inserts: *A*. Sprinkler head. *B*. Sprinkler head in action.

A coin or other metal under a fuse removes the protection the fuse is supposed to give. If a second fuse blows as soon as it is put in, it shows that there is still a short circuit somewhere. Replace the fuse with an electric-light bulb. This will be lighted as long as there is a short circuit. Hunt up the short circuit; when found and removed the

lamp in the fuse box will go out. Then you can safely put in the fuse.

Short circuits in the automobile cause many of the automobile fires. The constant vibration may wear the insulation from the wires or even cause them to break. The insulation may be saturated with oil or gasoline. When the bare wire touches the metal of the engine or chassis a spark results which ignites the oil and starts the fire.

Smoke flues. Smokepipes and chimneys often collect much soot. At times this may take fire, and a chimney fire may result, with the danger of sparks falling upon the roof. Smokepipes and chimney flues should be examined yearly and cleaned out if found coated with soot. Excessive heat in the chimney weakens it and increases the fire-hazard.

Water is the universal fire extinguisher. Water has many properties which make it an ideal fire extinguisher for large fires. It is cheap. It can be thrown long distances. High pressure, which can give it great velocity, can be secured by means of pumps. Water has great cooling power. It absorbs heat in being warmed and in being changed into steam. When water reaches the boiling temperature, 1 pound in changing to steam absorbs 956 times as much heat as is absorbed when this water is warmed 1 degree. In being warmed 1 degree, water absorbs more heat than the same weight of any other liquid or solid. If the fire is near live bare electric wires it is not safe to hold a hose and direct the stream upon it because the water can conduct the current back to the firemen. Dangerous and sometimes fatal shocks have occurred in this way.

Fig. 148. — Soda-acid extinguisher.

Automatic sprinkler system. Some schools and many factories have overhead water pipes in certain rooms and many sprinkler heads attached to the pipe. One type of sprinkler has a small piece of metal soldered to the sprinkler head to keep the opening closed. The soft solder has a low melting point, about 180° F. Hot gases from a fire soon open the sprinklers, which send sprays of water in all directions.

Soda-acid extinguisher. This extinguisher contains a solution (2½ gallons) of baking soda (1½ pounds), and a bottle half full of concentrated sulfuric acid (4 ounces). When the extinguisher is inverted the lead stopper of the acid bottle drops out and the acid comes in contact with the soda solution. The carbon dioxide gas which is immediately produced creates

enough pressure to throw a stream of liquid a distance of 30 to 40 feet. This is particularly good for wood, paper, textile, and rubbish fires. If you put half a cupful of vinegar into an 8-ounce bottle, add a teaspoonful of baking soda, and quickly close with a cork stopper, you will see bubbles forming, and soon they produce so much force inside the bottle that the stopper is blown out.

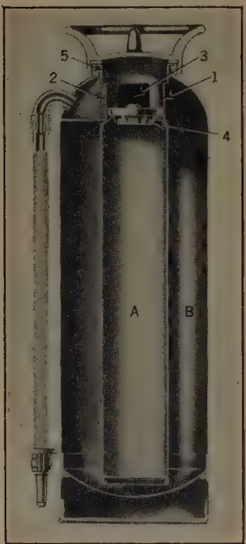


Fig. 149. — Foamite extinguisher. 1. Stopple cage. 2. Discharge screen. 3. Metered port openings for proper mixing solutions A and B. 4. Stopple seat. 5. Collar from which inner tube hangs.

Foam extinguisher. In this extinguisher aluminum sulfate acts upon baking soda and liberates carbon dioxide. Some other preparation such as licorice extract or gum arabic may be put in the solution to trap the small bubbles of gas as they form and produce a thick blanket of foam filled with carbon dioxide. This is useful on ordinary rubbish fires and is the best of all extinguishers for oil fires. The foam rides on the surface of the oil and effectively shuts off the air.

Vaporizing liquid extinguisher. Carbon tetrachloride, the safe cleansing fluid, is a dense liquid which vaporizes about as readily as gasoline. It will not burn or support combustion. Extinguishers containing this liquid have a pump so that the liquid can be forced out upon the fire. Its heavy vapor shuts off the air and smothers the fire. This is good for fires about electrical machinery and is the best available for gasoline fires. A small extinguisher should be carried in the automobile. It is also a good extinguisher for the kitchen, since it will extinguish oil and grease fires. The foam and soda-acid extinguishers are better for rubbish fires.

Carbon dioxide "snow." Liquid carbon dioxide under a pressure of 1000 pounds per square inch is contained in a strong steel cylinder. When the outlet valve is opened, the liquid runs out. The release of pressure causes much of the liquid to vaporize and expand. Both these processes absorb heat. They take so much heat that some of the liquid is frozen or solidified into tiny particles of solid carbon dioxide. This carbon dioxide snow having a temperature of —140° F. is thrown upon the fire. It has a tremendous cooling effect. As it is vaporized it pushes air away, and so it also has a smothering effect upon the fire. This

extinguisher is the best type for small fires about electric wires or electric machinery. The carbon dioxide is not a conductor of electricity and it does not wet the material which it touches. Carbon dioxide snow pressed into solid cakes, commonly called dry ice, is also a refrigerant.

FIG. 150.—"Foghorn" extinguisher using carbon dioxide "snow."

Safe house construction. Many fires start in the basement. Hot gases rise. Openings into partitions and outside walls act almost like chimneys in carrying the hot gases. If flames reach these spaces between the studding they can quickly be spread to all parts of the house. An old house can have these passages blocked by fire stops which means merely that the passages should be closed. A new house should be built with fire stops which prevent any circulation within the walls or under floors. Fire stops ought to be practically air tight and of incombustible material. The modern non-inflammable insulation within the outside wall also serves as a very effective fire stop.

Stairways are natural flues in which hot gases from a fire tend to rise. A fire-resisting door at the head of the cellar stairs will help delay a basement fire from gaining headway upstairs. Every house should have two means of exit from each floor, so that if one is blocked by fire there will be another way out. In many cities roofing material is required to be fireproof. This is a wise regulation because sparks from a large fire may at times be carried nearly a mile and start a fire if it falls upon inflammable material. Old chimneys should be inspected for cracks and repaired if defective.

Giving the fire alarm. The small fire is easily extinguished. Time lost in starting to extinguish a fire gives the fire a chance to increase. If a fire seems beyond your own power to extinguish you should lose no time in notifying the fire department. You can telephone the fire de-

FIG. 151.— The three most common types of fire alarm boxes, showing method of use.

partment, or you can send in an alarm from the fire box on the street. Every person should acquaint himself with the location of the nearest fire box and learn how to send in the alarm. When you pull down on the hook in the fire-alarm box you set into motion the mechanism that turns the wheels that sends the alarm to the central fire station. The wheel that makes electrical contact has, on its outer surface, teeth spaced at such intervals that the number of the box is identified. Suppose the box number to be 243; there will be two cogs near each other, a wide space, four cogs near each other, a wide space, three cogs near each other, and then a much wider space when the series two, four, three is sounded over again.

SUMMARY

1. The greatest fire hazards are matches, smoking, and defective heating equipment. Back of all hazards is carelessness in allowing conditions for these hazards to exist.

2. Fires may be extinguished by removal of any one of its essentials: fuel, oxygen, kindling temperature.

3. Oil for kindling and gasoline for cleaning are two dangerous hazards. They may not only start fires, but also cause terrific explosions.

4. Worn electric cords should be replaced, and inflammable material must not touch electric-light bulbs.

5. Cloth may be fireproofed so that it will be slow burning.

6. Many fires start in cellars. Inspect smokepipes, chimneys, and electric wires. Do not allow rubbish to accumulate.

7. Water is the best fire extinguisher for most large fires. It is not safe to throw a stream of water upon live electric wires.

8. Firefoam and carbon dioxide "snow" are best for oil fires.

9. The acid-soda extinguisher generates a gas under pressure, and this forces the stream of liquid upon the fire.

10. Carbon tetrachloride is useful for a small gasoline fire.

11. The walls of buildings should have fire stops to prevent convection currents from acting like a chimney and carrying hot gases and fire quickly from cellar to garret.

12. Everyone should plan, before there is a fire, just what he would do if fire should be suddenly discovered.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Forest fires.
2. Fourth of July dangers.
3. The great Chicago fire of 1871.
4. The fire-fighting equipment of my town or city.
5. Dangers for fire-fighters.
6. Collect newspaper clippings on fires for a month.

CHAPTER XIII

AIR CONDITIONING AND VENTILATION

In order that a person be kept in health as well as comfort, the body must not vary much from its normal temperature of 98.6° F. Oxidation of food within the body produces heat in excess of the bodily demands. The surplus heat must be removed. The constant removal of surplus heat is just as essential as eating or breathing. The rate of heat loss from the surface of the body is determined by three conditions of the surrounding air, namely: its temperature, its humidity, and its movement. The temperature of the air, walls of the room, and objects in the room determine loss of heat by conduction and radiation. The dryness of the air determines the amount of heat lost by evaporation from the moist skin. Dry air (low humidity) and movement of air promote evaporation and cooling.

A cold climate and no artificial heat may cause an excessive loss of heat which interferes with normal body functions and lowers one's resistance to disease as well as making one uncomfortable. It is necessary, therefore, at times to have available some artificial heat. In a hot climate heat may not be removed fast enough for comfort, and some means of artificial cooling is desirable.

Complete air conditioning. Four factors or conditions of air which affect our comfort are: **temperature, humidity, air movement,** and **air purity.** Air conditioning is the process of altering one or more of these four factors so as to produce a condition of air which affords more comfort to the body. Means of control of all four factors gives complete air conditioning.

Kind of air conditioning depends upon location. During the winter in our northern cities, as New York, Chicago, Milwaukee, and Minneapolis, the important needs of air conditioning are: removal of dust, and heating, adding moisture to, and circulating the air. During the summer, conditioning is desirable for a part of the time, but it is not generally considered so important.

In our southern cities, as, Jacksonville, New Orleans, and Dallas, there is more need of summer air conditioning. It is true that for short periods of time some artificial heat is needed in the winter, but humidity is not objectionable then. In the summer, for a large part of the time, cooling and removal of moisture are necessary for bodily comfort. It

is desirable at all times to remove dust and odors by washing the air. But temperature and moisture control are the two important factors to provide for, if complete conditioning is impossible.

In the southern states removal of moisture from the air in summer will add greatly to one's comfort. Summer cooling and reducing humidity require a heat-absorbing device. Removal of heat both cools the air and causes condensation of moisture. A chilled surface in contact with the air will do this. In hot, dry countries where evaporation is rapid, sprinkling the roof of a house produces a desirable lowering of temperature. Regions between our northern and southern cities require year-round air-conditioning plants.

The body radiates heat. Experience has shown that, when many people gather in a small room artificially heated, it is well to cut down the heat a little, else it will soon be uncomfortably warm. Heat given off by the people raises the temperature. Every person and every object is constantly radiating heat. Likewise, they are all the time absorbing radiant heat which they receive from other objects. If you stand close to and facing a hot chimney or stove, you feel the heat because you receive more radiant heat than you give off. But if you stand close to and facing the window when it is very cold outside, your face feels colder. This is because you are sending out more radiant energy than you receive from objects outside or from the glass itself.

In a room with cold furniture and very cold walls, the exchange of heat is unfavorable to the body, and even if the air is hot you feel "chilly." If the walls are very hot, the air must be much cooler to make you comfortable. If they are both hot the body cannot lose enough heat to be comfortable. Experiments have been tried by having resistant electric wires woven into wall coverings of panels behind which hot-water pipes absorb heat and retain it for a long period. When the walls are kept at 80° F., which is about the temperature of the surface of the body, and the air temperature is 55° F., a person is comfortable.

Temperature of the air. Since the normal temperature of the body is 98.6° F., the air, if it removes any of the body heat by conduction, must be at a lower temperature than that. As a rule, our own natural surface temperatures are lower than 98.6° F. Many people wear heavier clothing in winter than in summer. The average person is comfortable under a slightly higher temperature in summer than he is in winter. Most homes are provided with various devices for warming the air, such as small heaters when but little heat is desired and large furnace-type heaters capable of warming the house in extremely cold weather. It is possible not only to raise the temperature of the air

when it is cooler than desired but also to cool the air when it is too warm. The cooling of hot air in summer has been practiced for many years in some stores and theaters, and devices are available for anyone who wishes to install them in the home. The air is passed over a cold coil

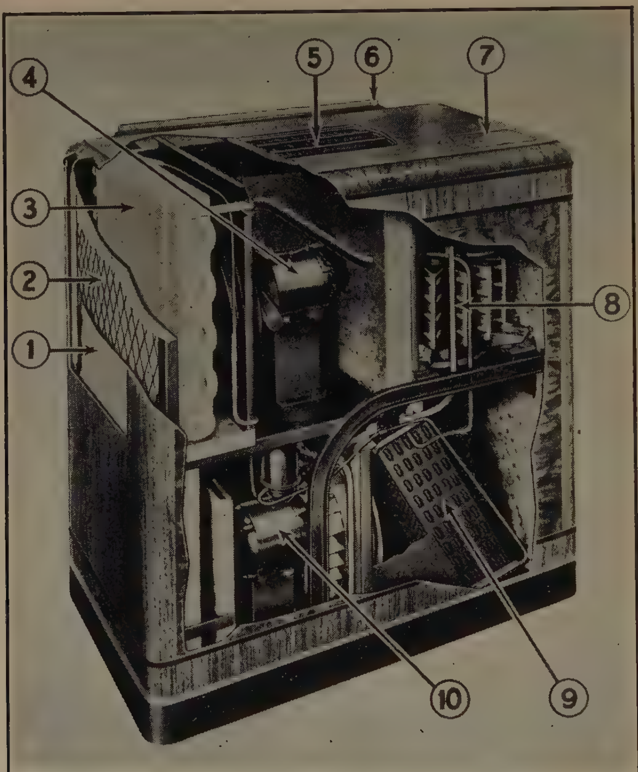


FIG. 152.—A self-contained air-conditioning unit. (1) Return air inlet grille. (2) Air filter. (3) Cooling and dehumidifying. (4) Air circulating fan for room air. (5) Inlet grille. (6) Outdoor air connection through window duct for ventilation and removal of heat and moisture from the room. (7) Concealed comfort control panel containing thermostat and ventilation dial. (8) Frigidaire Meter-Miser mechanism. (9) Finned tube condenser. (10) Fan and Delco motor to circulate outdoor air through unit and remove heat and moisture picked up by cooling coil from room air.

similar to that in the cold chamber of the refrigerator and after being chilled is forced by means of an electric fan through a duct to the room to be cooled. A device which can be placed in the room is also available. It takes no more room than a refrigerator, and a current of cool air issues from it as long as it is kept in operation.

The effective temperature of the air. The temperature recorded by the thermometer may not be the effective temperature of the air upon the body. If two thermometers are hung in the room but one of them has a piece of wet muslin covering its bulb, you know from your previous study that the one with the wet bulb will, unless the air is saturated, read lower. The evaporation of water on the surface of the bulb makes the effective temperature of the wet body lower. The human skin is excreting water over the whole surface of the body. If the air is unsaturated, some, perhaps all, of this water will evaporate and make the effective temperature at the surface of the body lower than if no evaporation took place.

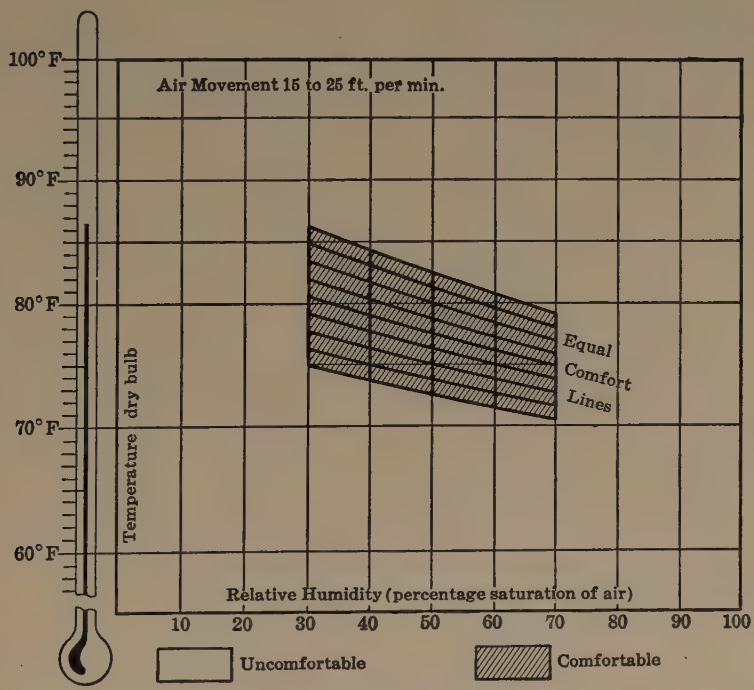


FIG. 153. — Equal comfort lines.

Air conditioning and comfort. According to tests made upon hundreds of people, it has been found that the conditions for comfort vary a little in summer from those in winter. A proper combination of temperature, humidity, and air movement is essential, but many combinations give out practically the same degree of comfort. The diagram "the comfort zone" includes combinations which have been

found by experiments to give comfort. That part of the comfort zone most desirable at any given time may depend upon outside conditions. If the outdoor temperature is 20 degrees colder than that inside, the body suffers a severe shock upon entering or leaving the air-conditioned room. The lower comfort lines would therefore be better for winter, and the upper ones for summer.

Motion of the air. It is a matter of common experience that air at the freezing point, 32° F., in a strong wind produces more discomfort than quiet air at 12° F. The moving air produces a cooling effect by bringing more air into contact with the body and thus increases the loss of heat by conduction and also by promoting greater evaporation of moisture. This principle is demonstrated by hanging a wet-bulb thermometer in a room. Record the lowest temperature it registers. Then while it is still wet fan it vigorously, and you will find that it drops several degrees. In quiet air, evaporation of moisture charges the air around the bulb with moisture so that evaporation is checked. A wind replaces the moisture-laden air with drier air which allows evaporation to go on more freely with the consequent reduction in temperature.

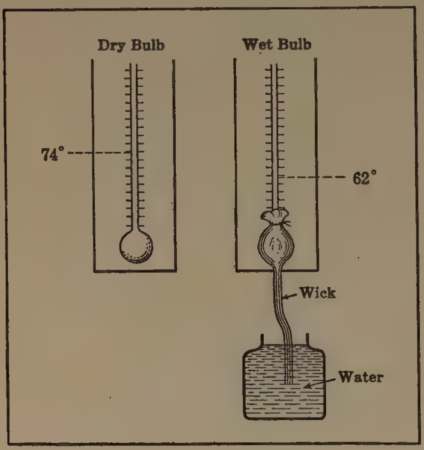


Fig. 154. — Wet-and-dry-bulb hygrometer. Evaporation is a cooling process.

Humidity and furnace heat. In those seasons of the year when we use no artificial heat, we cannot easily change the humidity of the air. On excessively hot and humid days in summer, we would like to remove the moisture. This can be done with a refrigerating outfit or some other dehumidifying device. In winter in our northern states the cold air has very little moisture in it. When this air is heated, the relative humidity drops and at times the air in our houses is drier than the air on the desert.

In most of our hot-air furnaces there is a water tank to supply water to the air which is warmed and sent to the rooms. This tank, under ordinary conditions, does not supply one-tenth of the moisture needed to make the air comfortable and healthful. It is impracticable to have much above 40 per cent relative humidity in cold weather, because of the excessive condensations on cold surfaces such as walls and windows.

Damp walls and frosted window panes often result when the moisture in the air is just right from a health standpoint. In order to maintain a humidity of 40 per cent in the average-sized, well-ventilated house

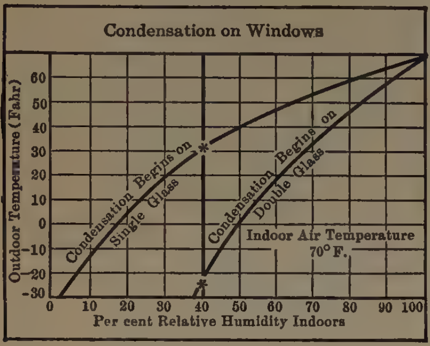


Fig. 155. — Graph showing effect of double windows upon indoor humidity.

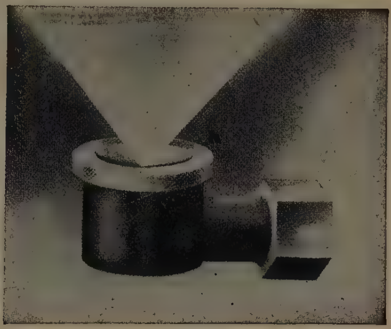


Fig. 156. — A water spray is sometimes used in the hot-air chamber to increase the humidity.

heated by warm-air furnaces in very cold weather, 8 or 10 gallons of water must be evaporated each twenty-four hours. With the proper

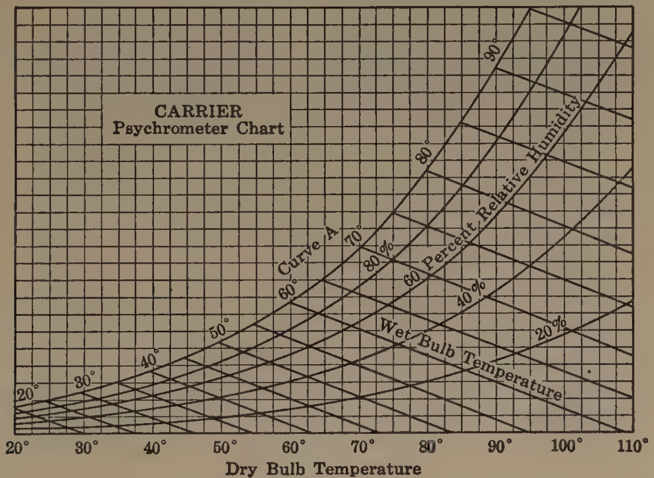


Fig. 157. — A psychrometric chart used in determining the relative humidity from readings of wet-and-dry-bulb temperatures.

humidity, the room is comfortably warm at a temperature several degrees cooler than when the air is dry.

The average person in good health can endure a humidity even down to 20 per cent for short periods of time without serious danger to

health; however, for comfort and health insurance, it is wise to keep it as high as 40 per cent in the winter.

Simple means of ventilation. With fire in a fireplace ventilation is good because much air, in excess of that required for burning the fuel, escapes up the chimney. Fresh air enters through cracks about the doors and windows, and may even come, to some extent, through the walls. A stove gives very little ventilation, because not much air is carried up the chimney. The air supply, in warm-air furnace heating, gives ample ventilation, if the supply is drawn from out of doors.

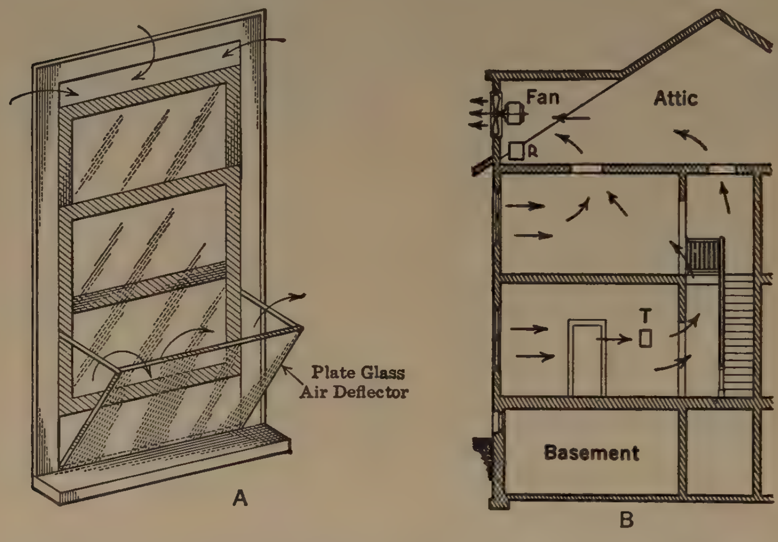
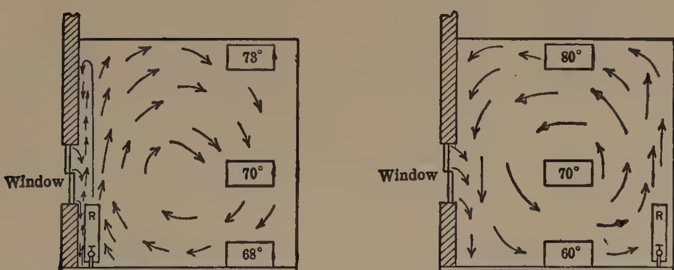


Fig. 158.—*A*. Ventilation without a draft. *B*. Circulating hot summer air for greater comfort.

Since the warmer air is in the upper part of the room, opening the window both at the top and bottom will effect a natural circulation. It is well to have some deflecting surface to meet the entering air, and prevent a direct draft into the room, as in Fig. 158. If the air is deflected upward, it will diffuse more readily, and a person in front of the window will be protected. Plate glass makes a good deflecting surface and has the added advantage of permitting light to enter undiminished. Kitchen odors may be removed by having a fan set in a panel above the window as shown in Fig. 159. It is better to place a radiator under a window than against an inside wall, as this insures more even distribution of heat in the room, as is shown in Fig. 160.

FIG. 159. — Window fan and panel and its use in the kitchen.



Radiator properly placed.
A fairly uniform temperature results at different levels.

Radiator improperly placed.
Wide differences in temperature result at different levels.

FIG. 160. — Importance of the position of the radiator.

Mechanical ventilation. So far we have considered methods of ventilation in which the movement of air was effected naturally, by gravitation, as in the majority of our homes. The gravitation system works best in cold weather; in warm weather there is very little circulation of air through the house. In large buildings, schools, halls, and factories, natural or gravity circulation of air is not satisfactory, and some method of mechanical ventilation must be employed. Often an indirect heating system is used in which air is forced to circulate by

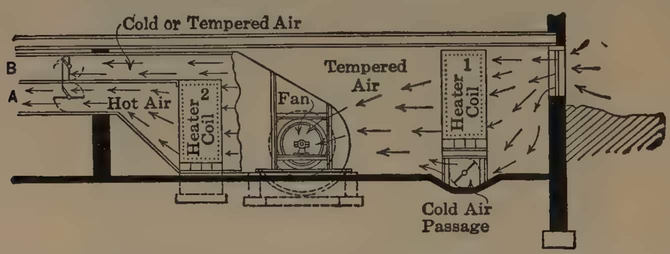


Fig. 161. — In a mechanical ventilating system it is possible to change the condition of the air at will.

means of a " blower " or enclosed fan, as in Fig. 161. This system of securing ventilation is frequently combined with either the hot-water or steam heating system, in which radiators are placed in the rooms. With this combination, only enough air is circulated to secure satisfactory ventilation. This system has an advantage for schools and factories, in that the fan circulation of air may be stopped when the occupants have left the building. The separate heating system makes it possible to keep the building warm without the circulation of air.

Systems of mechanical ventilation. When air is forced into the rooms by fans located in the basement, the pressure indoors is slightly greater than atmospheric. This **pressure system,** sometimes called the **plenum system,** gives a positive circulation of air under all weather conditions. Because of the great pressure, some air escapes from the rooms through cracks around doors and windows, but none enters through these places.

When air is drawn from a building by fans placed at or near the top of the ventilating flue, the pressure in the rooms is slightly less than atmospheric. This is the **exhaust or vacuum system.** Air passes into the room through the air ducts, but it also comes in through cracks and crevices. For this reason, as a rule, outside weather conditions interfere with an exhaust system more seriously than with a pressure system.

Air-mixing system. When the heating is done entirely by the circulation of hot air, it is necessary at times to admit air at a lower temperature. This is made possible by having two heating stacks and two air ducts, as shown in Fig. 161. Cold air passes over heating stack 1, and becomes "tempered air." The fan draws air from the tempered-air room and forces a part of it over heating stack 2, which produces hot air in duct *A*. The other portion of the tempered air passes from the fan to duct *B*. The hot and cool (tempered) air may be mixed in any proportion, or either supply may be entirely shut off from the room by means of the mixing damper.

Inlets and outlets. Fresh air can be properly distributed in the room only by an adequate arrangement of inlets and outlets. It takes time for new air which has been brought into a room to diffuse and dilute other air already there. If the hot air enters near the floor and leaves near the ceiling, it will pass through the room so rapidly that little diffusion will take place, and the escaping air will consist, for the most part, of the pure air which has just entered.

When the inlet is near the ceiling and the outlet is near the floor on the opposite side of the room, Fig. 162, a large portion of the air in the room remains stagnant. When the inlet is near the ceiling and the

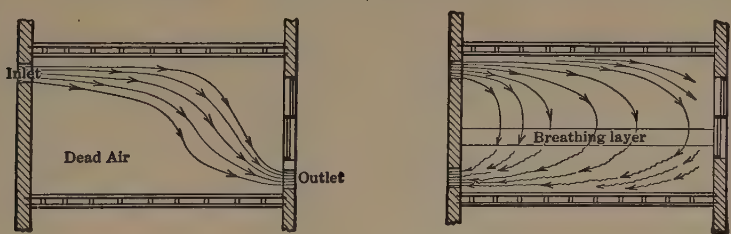


FIG. 162. — Good and bad ventilation practice in schools.

outlet at or near the floor on the same side of the room and diagonally opposite to the inlet, gradual settling, diffusion, and mixing result, so that practically all parts of the room are benefited by it. The inlet and outlet should be in the inner wall rather than in an outside wall.

Recirculated air. The discharge of all the hot air from a room into the outer air and the heating of other, fresh air to provide ventilation requires a large consumption of fuel. Experiments indicate that a saving may safely be made by recirculating the air. If the air is filtered and washed, its impurities are removed in a large measure, but, as it is not cooled to a very low temperature, the reheating requires little fuel. In tests made in schools, pupils have been found to do practically as good work in recirculated air as in fresh air. Odors are more noticeable

in recirculated air than in fresh air; the amount of carbon dioxide may be increased to ten times that in normal air, without harm.

Objections to recirculated air. Recirculated air, under ordinary conditions, contains more bacteria than fresh air brought in from out of doors. Unless the washing process is carried out with great care, there is danger in using recirculated air in public buildings. If air is properly filtered this danger is removed. Outdoor air, under the action of ultraviolet rays, acquires a property difficult to describe, but which we may call *active*. This active property is lost when the air is breathed. Window glass excludes most of the ultraviolet rays, so that sunlight in the house cannot revivify the air which has once been polluted by breathing.

Cloth window ventilation. The substitution of thin, stout cloth for the glass of windows has been tried with good success in sleeping rooms and hospitals. The cloth frees the air from dust, and allows a slow movement of the air, preventing drafts. This system of ventilation also helps to secure outdoor humidity.

Air conditioning and health. In spite of many humidifying devices in use, the fact remains that the air in the artificially heated house is abnormally dry in the winter. Air at ordinary room temperature with a relative humidity of 20 per cent or under is able to absorb a large amount of moisture from any moist surface with which it comes in contact. The skin of the body and the air passages are sources of moisture for this dry air. Evaporation of moisture from the membranes lining the respiratory tract, into the dry air we breathe, dries them excessively. The lining of the nose dries out so that its efficiency as a filter of dust and germs is greatly reduced. Dry air has more dust and therefore more bacteria floating in it than moist air. It has been found by the U. S. Health Service that respiratory diseases increase during the winter in the period when artificial heating gives us the driest air in our homes.

In contrast with excessive evaporation from the normal body in a dry atmosphere is the absence of evaporation when one is sick with fever. During a fever the skin is dry because abnormal conditions have closed the pores in the skin. Evaporation of moisture from the skin, which normally removes the surplus body heat, stops, and there is a rise in body temperature. Many diseases are accompanied by fever. The body temperature is one of the important indications of the patient's condition. Not only does excessively dry air have a debilitating effect and increase one's liability to disease, but it also makes one more irritable.

Air conditioning should add moisture to the dry air of winter and

remove moisture from the moist air of summer. Not only does the purified air give more comfort but also it helps protect one from germ diseases and sometimes offers great relief to sufferers from hay fever and asthma by removing the pollen which brings on attacks of these diseases. Incidentally, it is claimed that the fresher complexion of the women in England and Ireland is due to their living in an atmosphere having a higher humidity than ours.

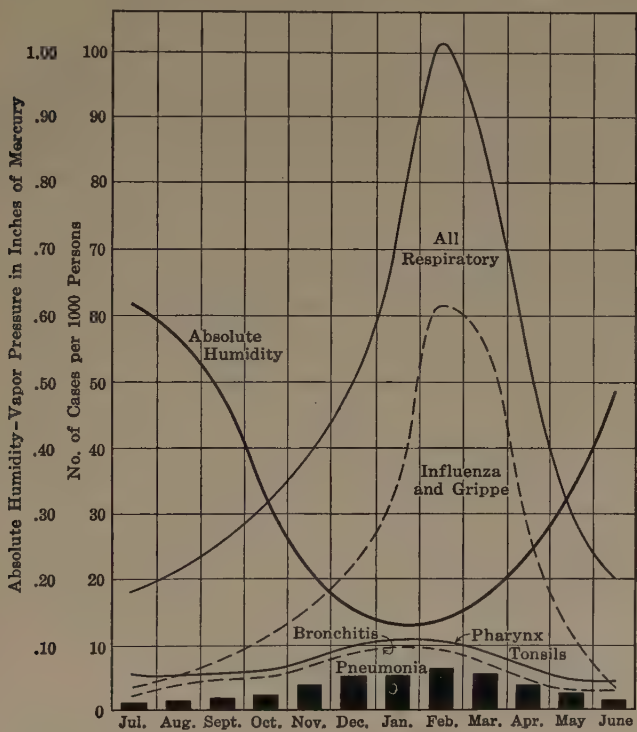


FIG. 163. — Chart showing the relation between too dry air and certain diseases, based on conditions in New York City.

Control of moisture in the industries. For many years, the amount of moisture in the air has been controlled in some industries, as spinning and weaving, candy-making, and the manufacture of telephone toll cables. In the spinning room the humidity must be kept high, but in the cable manufacture it must be kept low. At times moisture must be added to the air. This can be done by passing the air entering the room over wet surfaces or air washers. At other times moisture must be removed. There are two processes for this: (1) refrigeration; (2) ad-

sorption. In the refrigeration process, air is cooled by artificial means until the excess moisture is condensed, and the dehumidified air is then reheated. In the adsorption process, filtered air is sent through layers of porous prepared silica which by adsorption will take moisture from the air up to 40 per cent of the weight of the silica. The air current is then shifted to another set of silica beds while the moisture is driven out of the first by heat. The moisture may be removed by either process to any desired humidity.

Purifying the air. After being shut up in the house for a few days, one longs to go out of doors for a walk to get some "pure fresh air."

Besides the essential elements and compounds that make up air, there are, in almost all outdoor air, many foreign substances. When outdoor air is filtered through several thicknesses of fine cheese-

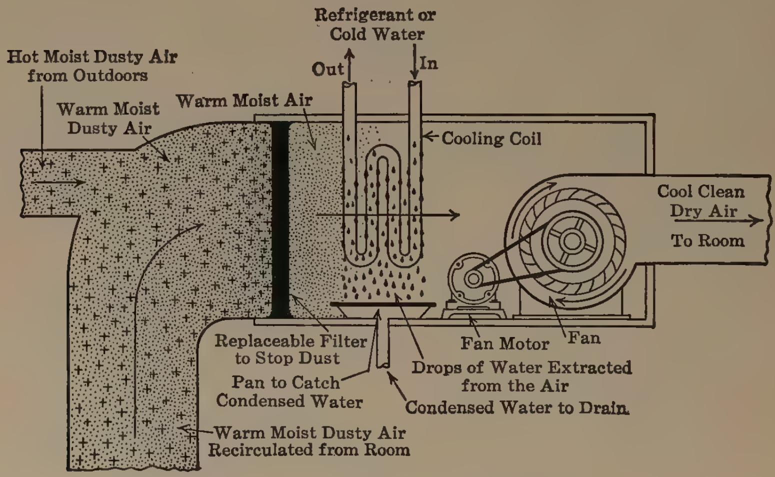


FIG. 164.—Purifying recirculated air.

cloth much dust will collect on the cloth. If the dust is examined under a microscope, it is seen to contain grains of rock powder, black specks of carbon, lint from clothing, bits of crushed dried leaves, pollen from grasses, weeds, and garden flowers, living germs, and spores of molds. If the air were carefully washed you might find that the wash water was acid. The washed air might also have lost a disagreeable odor that outdoor air occasionally has. When air has been effectively filtered, it has been found that about a pint of dirt is removed per week from the air used in the average home. All these impurities can be removed from air that undergoes a complete process of conditioning.

Air can be cleaned by several methods: by water spray, by filtration through cloth screens, steel wool, or glass wool, and by passing it over a series of wet baffle plates which collect the dust particles.

FIG. 165.—Conditioned air is distributed through the same metal ducts both winter and summer. Observe that either fresh outdoor air or recirculated air may be used.

Household air conditioning. Modern homes are heated automatically during cold weather by passing heated air through ducts into the different rooms. Equipment can be procured so that in hot weather cooled air may be circulated through those same ducts. Too little attention has been given to the moisture content of the air. Frequently it is far too low in winter and too high in summer. By installing an air

washer and dehumidifier it is possible to change the humidity either way and secure a comfortable, health-producing atmosphere in the house. Such devices are already in use in many large office buildings and hospitals. Figure 166 shows a hospital unit for the treatment of pneumonia. Not only can the quality of the air (purity, temperature, and humidity) be controlled, but also the oxygen content may be increased and the carbon dioxide reduced as the physician desires. Air

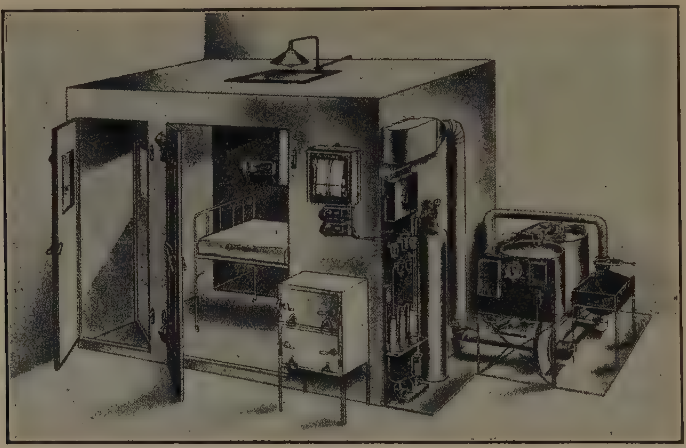


FIG. 166.—A one-room hospital unit showing the simple and compact silica gel atmosphere-control equipment for the treatment of pneumonia.

conditioning is also important because too dry air causes furniture to dry out and loosen, windows and doors to shrink, and plants to wither and die.

Summer conditioning of air now possible. Man has known how to produce heat for a very long time, but knowledge of methods for the removal of heat is comparatively recent. In latitudes with cold winters man has become accustomed to the use of artificial heat in his home, but he is only just beginning to remove the excessive heat in the hot summers. It is not merely for comfort but also for bodily good health that much of the summer heat should be removed. Hot, dry air has stored sensible heat. The moisture in moist air has stored latent heat. The more moisture there is in the air, the less moisture can be evaporated from the skin of a person. When moisture does evaporate from the skin it takes in the latent heat which becomes stored in the moisture. The more evaporation from the skin, the greater will be the cooling effect.

Thus cooling the air and removal of moisture from it give the air

much greater ability to remove excess heat from a person and so add to his comfort and health. Filtering the air to remove dust, dirt, pollens, and germs also improves its healthfulness. Commercial devices for air conditioning are coming into use rapidly. There are units for single rooms, for two rooms, or for a whole house. It may not be long before conditioning air will be considered almost as essential for summer as for winter.

SUMMARY

1. Complete air conditioning involves control of four factors, namely: temperature, humidity, air movement, and air purity.
2. The type of air conditioning most needed varies with location.
3. More heat is generated in the body than is needed. The excess is removed by evaporation of moisture by radiation and by conduction.
4. Heating cold air already of low humidity greatly reduces its relative humidity. For comfort and health, moisture should be added to this air.
5. When the air is very dry, excessive evaporation from the skin makes the effective temperature of a room lower than the dry-bulb temperature.
6. Motion of air promotes cooling both by increasing conduction of heat and evaporation of moisture.
7. Ventilation is the means of bringing a supply of fresh air to the occupants of rooms. Ventilation is accomplished by natural circulation, by drafts caused by fires in fireplaces and stoves, and by forced ventilation by means of fans.
8. In large buildings, mechanical ventilation is essential. In the *plenum system,* the air is pushed into the rooms by a blower. In the *exhaust system,* air is drawn from the room by means of a fan.
9. The best arrangement of inlet and outlet in a mechanical system is to admit air near the top of the room and to have it escape near the floor on the same side as the inlet and diagonally opposite.
10. Sometimes air from the rooms is returned to the heater and recirculated. This will save fuel in cold weather, but if many people occupy the rooms it is not satisfactory. If the recirculated air is washed and filtered, it may be used without harm.
11. Very dry air promotes respiratory diseases.
12. Moisture can be added to the air by passing it through air washers.
13. Moisture can be removed from the air in our houses by refrigeration and by adsorption.

14. Cooling plants as well as heating plants are available for use in our houses.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Natural vs. mechanical ventilation.
2. Advantages and disadvantages of recirculated air.
3. Compare the time of drying a wet cloth in still air and in moving air. (Use an electric fan.)
4. Test ventilating openings — window cracks, high and low; doors, top and bottom — to determine the direction of air movements in a room.
5. Cost to air-condition your home in summer.

CHAPTER XIV

ICE AND REFRIGERATION

Preserving food by heat cooks the food and, because of certain chemical changes, gives the food a different flavor from the original. Food preserved by cold retains more nearly its original flavor and texture.

The earliest method of cooling to be extensively practiced was evaporation. Water which oozes through a porous earthen vessel or skin carries away heat as it changes to a vapor and thus it cools the

Photographed by Ewing Galloway.

Fig. 167.—Filling goatskin water bags. Evaporation from the outer surface cools the water.

contents. The ancient Greeks and Egyptians followed this method, and the iceless refrigerator of today employs the same principle. Cellars, wells, and springs of cold water from the earth are still utilized in rural communities for keeping foods. When snow and natural ice have been available, they have been used. The harvesting of ice in

winter and storing for summer dates from about 1800 in this country. Ice famines sometimes occurred because of a mild winter.

A machine to manufacture ice artificially was invented in 1775 in England, but it was not until about 1890 that artificial ice became an important factor in refrigeration in America. Now, not only is artificial ice available in any quantity for home use, but the principle of cooling has been applied to great food warehouses, so that practically any food may be preserved for a long period of time in cold storage. Seasonal excess food products can be held over for the time when there is little or no production, so that almost all foods can now be obtained at any time of year.

Sources of ice. Not many years ago, Florida and other states, where the climate is too warm to provide natural ice, secured their supply from Maine and other northern states. The ice was cut from ponds, lakes, and rivers. The harvesting of natural ice is still an

FIG. 168. — Bringing ice from the field to the ice house. Ice going through the saws.

important industry in the north temperate latitudes, but comparatively little is shipped to warmer latitudes. Ice can be manufactured more cheaply than it can be harvested and shipped. The artificial ice industry has had an enormous growth within the last 35 years, and artificial ice now competes with natural ice even in the cold climate of our northern states. The making of artificial ice is under such control that a more uniform and purer product may be secured, whereas the quality of natural ice depends upon the source and upon weather conditions. A pound of artificial ice will give exactly the same cooling effect as a pound of natural ice. Since ice is of such importance in our daily life, we may well inquire why it is of such value to us. Is it because it is cold? Will a pound of water which is just as cold as ice give us the same cooling effect? Are there any substitutes for ice?

Cooling effect of ice. Experiment shows us that when 1 gram of ice at 0° C. is put into 2 grams of boiling water (100° C.) the temperature which results at the time the ice is all melted is 40° C. If, however,

1 gram of water at 0° C. is used in place of the ice, the resulting temperature is 66⅔° C. Cooling results because heat is taken by one body from another. Since the ice cools the boiling water more than the cold water does, it must absorb more heat. You probably suspect that this additional heat absorption comes from the melting of the ice.

Heat required to melt ice. If two pans are placed on a stove which is evenly heated, and a pound of ice at 32° F. is put into one pan and a pound of water at 32° F. into the other, it will be observed that, at the instant the ice is completely melted, the temperature of the water in the other pan is at about 176° F. We may assume that the ice has absorbed practically the same quantity of heat as the water. Hence, it requires as much heat to melt 1 pound of ice as to warm 1 pound of water from 32° F. to 176° F., or 144 degrees. In order words, it requires 144 B.t.u. If we had used such small amounts as 1 gram each of ice and water at 0° C., we should have found that it took as much heat to melt the gram of ice as to heat the gram of water from 0° to 80° C., or 80 calories. This is a crude method of measuring heat of fusion, but 80 calories per gram is the result found by more refined methods. These 80 calories of heat are absorbed and become *latent* or *hidden* in the molecules of water, for they produce no rise in temperature. Therefore, when 80 calories of heat are added to 1 gram of ice at 0° C., 1 gram of water at 0° C. is produced.

The heat of fusion of ice is 80 *calories per gram.*

Expressed in English units, *the heat of fusion of ice is* 144 *B.t.u. per pound.*

PROBLEMS

1. A farmer put 300 lb. of water at 150° F. into a tub in his cellar on a cold night. In the morning he found that two-thirds of the water had been changed to ice. How much heat (B.t.u.) was given to the cellar?
2. How many calories of heat are necessary to change 50 gm. of ice at 0° C. to steam at 100° C.?

Melting points. Most crystalline substances, like ice, sulfur, and salt, when heated until they liquefy, change abruptly from solids to liquids. Such substances have a definite *melting point.* Other substances, as sealing wax, tar, glass, and wrought iron, soften gradually under the application of heat. There is no one definite temperature at which these substances change from a solid to a liquid. If snow is brought from out of doors, when the air is at a temperature of —10° C., into a warm room, the snow is first warmed until its temperature is 0° C. A thermometer will indicate this rise in temperature. If we now place this vessel of snow on a hot stove, we shall find that the snow gradually

changes to water, but the thermometer does not indicate any increase in temperature. Not until all the snow is melted does the temperature rise above 0° C. Then, as heat is added to the water, the temperature rises.

TABLE XVII

MELTING POINTS

	Fahrenheit		Fahrenheit
Alcohol	−173°	Copper	1893°
Mercury	−39.5°	Glass	2012°
Sea water	27.5°	Iron, cast	2102°
Ice	32°	Steel	2606°
Olive oil	39°	Iridium	4172°
Phosphorus, yellow	111°	Butter	90°
Phosphorus, red	1337°	Lard	96.8°
Sulfur	248°	Soft paraffin	122°
Tin	449°	Hard paraffin	136°
Solder	464°	Cane sugar	320°
Lead	651°	Tallow	82°
Aluminum	1218°	Tungsten	6119°
Silver	1762°	Camphor	348°

It is observed that we may have ice or snow at 0° C. or we may have ice or snow and water mixed together at 0° C. If heat is applied, all the solid is first changed to liquid at 0° C. Hence, 0° C. is the melting point of ice. When water is cooled, it is found to solidify or freeze at this same temperature, 0° C., until all the water is frozen. It is possible, however, for pure water which is kept perfectly quiet to cool a degree or so below 0° C. before ice crystals start to form, but if the liquid is jarred it quickly freezes and acquires a temperature of 0° C.

Change of volume during melting and solidification. The tremendous expansive force of water during its solidification is brought to our attention when the water pipes freeze in winter. The fact that water expands upon freezing, though it has many disadvantageous features, does have important advantages. It helps to tear rocks to pieces and so makes soil, and to make the soil better adapted to plant life. The frost in the ground loosens the soil every winter, as may be seen by observing the garden in spring. Since the volume of ice is greater than that of the water from which it is formed, its density must be less than that of water. Consequently, ice floats in water. The expansion is about one-ninth, and so the greater bulk of floating ice is below water. If we freeze 92 cc. of water, we get 100 cc. of ice, and the pressure produced when the water is confined is so great that it will burst the thick walls of an iron container. When we freeze ice cream, the can must not be full to the top, else it will run over while freezing. When the house is piped, there should be numerous cut-off valves in the cellar,

so that, in extreme weather, it will be possible to turn off those pipes which are most exposed without interfering with the use of water in other parts of the house.

Type metal and iron expand upon solidifying. Advantage is taken of this property in making casts. When the liquid metal is poured into the mold, it expands upon solidifying and fills every detail of the pattern. Our coins must be made in a stamping mill, because copper, nickel, silver, and gold contract upon solidifying and therefore cannot make satisfactory casts.

The freezing of a pond or lake. As water in the lake cools, it contracts until its temperature reaches 39° F. (4° C.). Convection takes

Fig. 169. — This iceberg rises 200 feet above water and extends approximately 600 feet below water. Seven-eighths of its bulk is under water. This picture, supplied by the U. S. Coast Guard, shows a Coast Guard cutter on ice patrol.

the water at 39° F. to the bottom, and warmer water stays on top, but, after all the water is at 39° F., further cooling causes it to expand so that water below 39° F. stays on top. Consequently, when water reaches the freezing point, 32° F., it is at the surface where further heat removal causes ice to form. Before a pond or lake freezes over, all water must be cooled to 39° F., at which temperature water is at its maximum density (see chart, page 42) and some of the water must have become cooled to 32° F. Water at the bottom of a deep pond has a temperature of 39° F. whenever there is ice on its surface. In a large lake like Lake Superior, below a depth of 240 feet the water is at 39° F. summer and winter. Around Lake Tahoe in California the temperature may go as low as —20° F. in winter, but the water never freezes. This is explained by the fact that hot springs feed portions of the lake, and also by the fact that the water is deep and the cold period is not sufficiently long to cool all of it to 39° F.

A Cooling Mixture. Put a cupful of crushed ice into funnel *A* and a cupful of crushed ice mixed with 2 tablespoonfuls of coarse salt in funnel *B*. Support each funnel in a cylinder. Support thermometers so that their bulbs are in the center of each mass of ice (Fig. 170). Soon you will see that the water is coming faster into cylinder *B* than into cylinder *A*. More than this, you will observe that the temperature in *B* is much lower than that in *A*. The salt has hastened the melting of the ice and increased the absorption of heat. Heat is also absorbed in dissolving the salt. This demonstration shows why the mixture of salt and ice is used in freezing ice cream. Ice alone cannot produce a temperature low enough to freeze water. Ice cream cannot be kept solid by placing it on ice. If ice cream is to be kept several hours or overnight, it should be repacked in salt and ice or in the freezing compartment of the mechanical refrigerator.

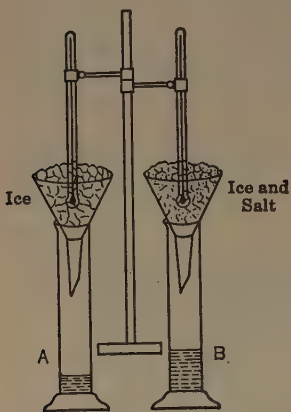


Fig. 170. — Cooling effect of (1) melting ice, (2) melting ice with salt added.

Freezing mixtures. The common household mixture for freezing ice cream is made of one part coarse salt with three parts crushed ice. Ice in contact with salt melts at a temperature below the melting point of ice alone. The resulting water dissolves the salt. Both the melting of ice and the solution of salt are processes which absorb heat, which is supplied by the surrounding materials and the solution itself. The outside container of an ice-cream freezer should be a poor conductor of heat, to prevent heat entering from the outside air. The inside vessel containing the cream to be frozen should be of metal, so that the heat may pass out quickly. Either ammonium nitrate or calcium chloride with ice or snow produces a freezing mixture capable of yielding very low temperatures. The cooling which results from solution of a salt is admirably shown by mixing 100 grams of ammonium nitrate with 100 grams of ice water in a calorimeter or a glass beaker. Pour a tablespoonful of water upon an empty crayon box and set the calorimeter into the water. Stir the contents, and as the nitrate is dissolved the calorimeter will freeze to the box.

Construction of the refrigerator. The usual household refrigerator is, in principle, a large box with thick, heat-insulating walls and with doors or covers to the several compartments within. One compartment is for ice. Experience has shown that the best results are obtained when

the ice chamber is at the top. The food compartments are below, or sometimes below and on one side of the ice chamber. Refrigerators are styled *top-icing, side-icing,* or *rear-icing,* depending upon the arrangement for placing the ice in the ice chamber. All the compartments are connected by air ducts so that there may be free circulation of air

FIG. 171. — (Left) Stirring ammonium nitrate in water. (Right) Beaker is frozen in water.

throughout the entire refrigerator. The lining of refrigerators is important. The metal zinc is used in cheaper grades. When old the metal lining becomes dingy and is often coated with enamel paint, but this soon is scratched and is not easily cleaned. The most satisfactory surfaces for linings for appearance, ease of cleaning, and sanitary reasons are enamel and porcelain.

Refrigerator trap. In the ice refrigerator, the water from the melted ice and the condensation on the ice of moisture from the air are removed from the refrigerator through a drain pipe to a pan placed beneath the refrigerator. The chore of emptying the pan may be avoided by having the pipe discharge out of doors in the country or into the sewer in the city. At the bottom of the refrigerator there is a bell trap similar in structure and operation to the one commonly used at the sink outlet. It is necessary to keep this trap and the pipes clean, else they will clog

and stop the discharge of water. The water seal in the trap prevents a back flow of gases or of warm air into the refrigerator and the loss of cold air out of it.

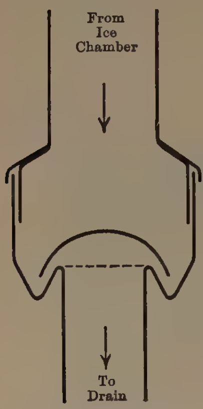


FIG. 172.—Refrigerator trap.

The refrigerator wall. Some of the heat that melts the ice in the refrigerator comes from the food, some from leakage of air around the doors, some from air which enters when the doors are opened; but the greater amount of entering heat which lowers the efficiency of the refrigerator is that which penetrates the walls. The composition of the refrigerator wall is, therefore, of much importance. Refrigerators have double walls between which are various other non-conducting materials, as felt, layers of paper, a packing of mineral wool, sawdust, ground cork, shavings, "dead air" space, etc. The layers in a satisfactory refrigerator may be as follows, beginning on the outside: wood, felt, air space, sheathing paper, felt, sheathing paper, waterproof paper, wood, air space, porcelain. For heat to enter through this wall, it must penetrate all these substances, and to some extent it will do so in spite of the very excellent insulators.

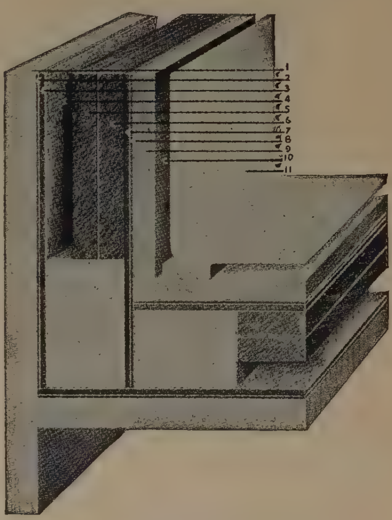


FIG. 173.—Wall construction of a refrigerator. (1) Wood sheathing. (2) Waterproof paper. (3) Woodfelt paper. (4) Air space. (5 and 6) Flaxlinum. (7) Woolfelt paper. (8) Waterproof paper. (9) Wood. (10) Dead air. (11) Porcelain enamel.

Air circulation in the refrigerator. Downward convection currents may easily be shown by the following experiment: Clamp an inverted cylindrical lamp chimney in a vertical position above the table. Place a cube of ice in the upper part of the chimney, supporting it, if necessary, on a piece of wire gauze. Close both ends of the chimney with rubber stoppers having short pieces of glass tubing passing through them, as in Fig. 174. By testing with smoke, it will be found that a current of air enters the top opening and comes from the bottom tube. If a thermometer bulb is held

at the opening of each of the tubes, it will be found that the air flowing out of the lower tube is colder than that entering the upper tube.

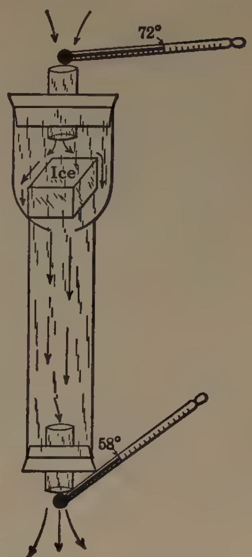


Fig. 174. — Principle of convection in the refrigerator.

When air comes into contact with ice in the ice chamber of a refrigerator, it gives up heat to the ice and becomes colder and denser, thereby sinking to the bottom of the ice chamber. An outlet at the bottom on one side of the chamber permits this dense, cold air to sink through a duct to the bottom of the refrigerator. Warm bodies continually give heat to the air. The refrigerator walls, the partition, and foods are constant sources of heat, for they never quite reach a temperature as low as the cold air from the ice chamber. As the cold air at the bottom of the refrigerator is warmed, it becomes lighter and is forced upward through the various food compartments, absorbing heat all the time. It finally enters the ice compartment at the top, where it is cooled again and starts on another journey through the refrigerator. Each time the air returns to the ice chamber, it gives up its burden of heat, which is carried off, stored as latent heat, in the drip water. Many of the foods

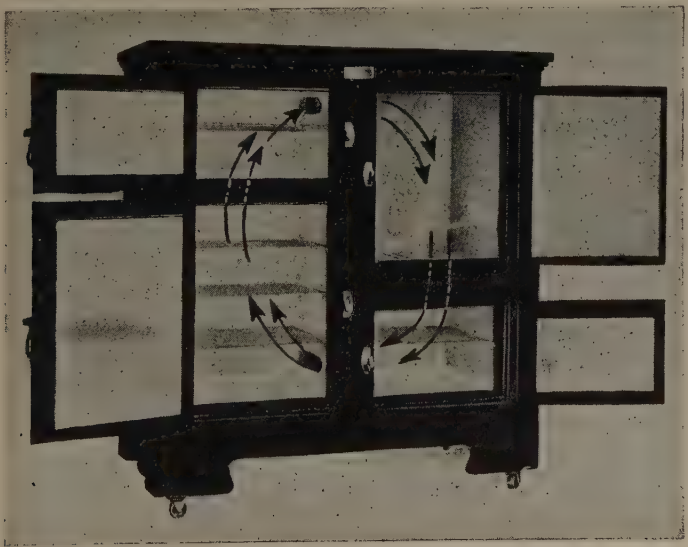


Fig. 175. — Circulation of air in the refrigerator.

give off water vapor, which is absorbed by the air. In the evaporation of water, the food becomes cooler because it loses just as much heat as the water vapor absorbs in changing from a liquid to a gas. Much of this water vapor is condensed to a liquid when the air comes into contact with the ice. Thus the heat of the water vapor is passed on to the drip water and removed from the refrigerator.

Humidity in a refrigerator. Since the capacity of air to hold water vapor is greater at a higher temperature, air in the food compartments of a refrigerator can hold more moisture than it can when it leaves the ice chamber. This gives the air a drying property which prevents the food compartments from becoming damp and moldy as long as there is a good circulation of air. The absolute humidity is lowest and the relative humidity highest in the ice chamber, near the cold air outlet. The relatively dry air passing through the food compartments aids in the preservation of food.

A cubic foot of air at 0° C. is saturated by 2.3 grains of water vapor, but at 10° C. 4 grains are required to saturate it. If a cubic foot of saturated air were to leave the ice at 0° C., and were warmed to 10° C. in the food compartments, it would be able to take from the foods 1.7 grains of water vapor. It would then return to the ice saturated or holding 4 grains, but, upon cooling in contact with the ice, it would leave the 1.7 grains of water on the ice. In this way the air acts as a carrier of water from the food compartments to the ice chamber, from which it escapes into the drip pipe. The fact that the air enters the food compartments with low relative humidity accounts for the dryness in the food compartments. If steaming hot foods are put into the refrigerator, more moisture will be given off than the air can absorb. Under these conditions the food compartments become wet, and foods do not keep well. The enormous amount of heat which the steam has stored in it, and which it liberates where the steam condenses, results in a great waste of ice.

In summer a cubic foot of air outside the refrigerator may have 10 to 15 grains of water vapor. When this air comes into the ice chamber, most of the moisture will be deposited on the ice. A cubic foot of air is saturated by 2.36 grains of water vapor at 35° F. When air is cooled to 35° F. in the ice chamber, it will deposit any water which it holds, in excess of 2.36 grains. As the cold, heavy air sinks into the food chambers, it is warmed. When half around its course, it may be at 45° F. Just before reaching the ice, the air may be 55° F., and each cubic foot can hold 4.8 grains of water. It is thus seen that the capacity of the air to hold moisture is doubled by its increase in temperature from 35° F. to 55° F.

Where to place food in the refrigerator. The coldest air in a refrigerator is in the bottom of the ice chamber and in the bottom of the refrigerator; the purest air (freest from odors) is where the cold air from the ice chamber enters the food compartment. This air also has least moisture. Certain foods, as milk, butter, and drinking water, if not tightly covered, will absorb odors; they should be placed in that part of the food compartment which first gets the air from the ice chamber. If in vessels that are securely closed, they may be placed in the ice chamber. Uncooked vegetables may be placed on the ice, as they give no odor to the air leaving the ice chamber. Sometimes food placed upon the ice will spoil. The warm air from the food compartment comes in at the top of the ice chamber, and when cooled will sink, so that often the top portion of the food placed directly upon the ice will continually be in warm air, and only the bottom layers will be kept cold. Keep fresh meats at the bottom of the refrigerator. Fish with the skin on may be packed in cracked ice in the ice chamber. If without skin and prepared for cooking, fish should be wrapped in a damp cloth and laid in the food compartment. In moist weather table salt may be kept dry in the refrigerator or by means of Cellophane covers.

The average temperature, in hot weather, of a well-kept refrigerator is 50° F. If a lower temperature is desired for any purpose, fill a basin half full of water and place several chunks of ice in this. Enclose the food in a sealed glass jar, and place the jar in the water in the basin. In this way the food may be kept ice cold. Oysters in bulk should be kept in this way. Some refrigerators have a "wet" compartment which holds water for this purpose. Fruit, eggs, and table "left overs" may be placed on the refrigerator shelf. In a side-icing refrigerator, vegetables should be placed on the top shelf; fruits, eggs, and "left overs" may be placed on the second shelf; meats, milk, butter, etc., at the bottom. Cellophane covers and bags are useful in the refrigerator.

Efficiency of the refrigerator. Perishable foods will keep in a refrigerator at 45° F. for several days. They will keep longer at 41° F. or lower. The lowest possible temperature to which the food compartments can be cooled is a little above 32° F., but temperatures below 41° F. are not easily or economically maintained in hot weather.

In a "heat-tight" space, foods once cooled would retain their low temperature without further ice consumption, but it is practically impossible to obtain such a space in a refrigerator. Warm air enters when the doors are opened; it leaks in at the cracks around the doors. Heat is conducted through the walls, for all matter conducts heat to some extent. The heat that leaks into the refrigerator in these ways is usually much more than the heat removed from the foods.

The efficiency of a machine *is the ratio of the useful work done to the total work expended.*

In the refrigerator the useful work is the absorption of heat from the food. The total work represents, in addition to this, the heat absorbed from all other sources necessary to the proper working of the refrigerator. If we regard the efficiency of the refrigerator as the ratio of the heat energy taken from the food to the total heat energy gained by the water resulting from melting ice, we find that, as a machine, the refrigerator has low efficiency. Of several refrigerators of the same size, filled with the same foods and with similar outside conditions, that one which will maintain a given low temperature in the food compartments

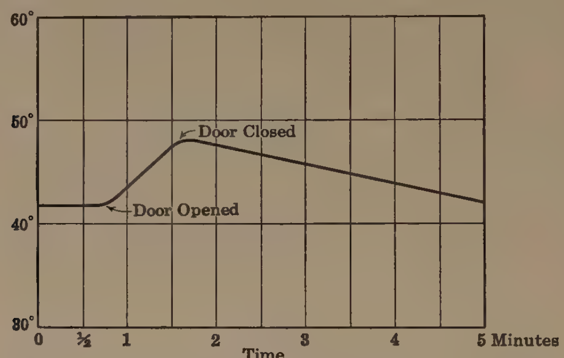


FIG. 176. — Graph to show temperature changes when the refrigerator door is opened and closed.

with the least consumption of ice has the highest efficiency. The efficiency varies with the quantity and kinds of food, the quantity of ice, the frequency of opening doors, the outside atmospheric conditions, and the construction of the refrigerator.

The heat loss due to entering air depends upon prevailing conditions and may be judged roughly by a consideration of the following data:

1 cu. ft. air at 86° F. (30° C.) cooled to 50° F. (10° C.) gives 160 calories.

1 cu. ft. air at 77° F. (25° C.) cooled to 50° F. (10° C.) gives 120 calories.

1 cu. ft. air at 68° F. (20° C.) cooled to 50° F. (10° C.) gives 80 calories.

The humidity of the air is even more important to consider, sometimes, than the temperature. For example, 1 cubic foot of saturated air at 86° F., if cooled to 59° F., will give up 9 grains of water. This will

give out about 320 calories of heat, or twice as much as the air gives up on cooling.

In a well-made refrigerator, whose doors are practically air tight, the heat coming to the refrigerator in the air which enters is not especially important, for it would take 75 cubic feet of saturated air, or 250 cubic feet of dry air, to melt 1 pound of ice. But in a poorly constructed refrigerator, even a small leak around the door causes a continual action of convection currents, and will cause a large interchange of air between the outside and the inside, with a resulting large loss of heat.

If large quantities of food of high specific heat are cooled, the useful work is large, but this does not affect the heat leakage through the walls; therefore the efficiency is higher with much food than with little food in the refrigerator. A small refrigerator, well filled with food, is more economical than a large one partly filled, for its efficiency is greater.

A small refrigerator should be considered fairly efficient, if it has an ice consumption of approximately $\frac{1}{200}$ pound of ice per hour per cubic foot, to keep the empty food compartment 1 degree Fahrenheit lower than the outside temperature. On this basis, to keep a food chamber of 5 cubic feet 20 degrees Fahrenheit below the outside temperature would require 12 pounds of ice, which, at 60 cents a hundred, would cost about 7 cents a day. With food in the refrigerator, the cost would be a little more than this.

It is poor economy to run the refrigerator on a small quantity of ice or to wrap the ice in a blanket. If it is desired to keep the ice, wrapping is the thing to do, but in this condition it will not keep the food compartment cool. If the ice does not melt, it cannot absorb heat.

The efficiency of the refrigerator depends to some extent upon its location. A special room just off the kitchen or dining room is desirable for the refrigerator; but it may be in the kitchen or pantry. The cellar is to be avoided because of dampness in summer, and the rear porch is open to objection because of the sun and weather. The refrigerator is as well and carefully made as the piano, and it should be given excellent care or it will warp, leak, and lose in efficiency.

The iceless refrigerator. Natives of hot countries, centuries ago, learned that water placed in vessels made of porous skins and unglazed earthenware became cooler after hanging or standing in the breeze for a time. The water very slowly penetrated the walls of the vessels and was evaporated at the outer surface. The absorption of heat during evaporation cooled the rest of the water. Many housekeepers know that a bottle of milk, set into a shallow basin of water and wrapped in a wet cloth which extends into the water, will keep better than if placed

entirely in the water. Here, again, evaporation of water produces cooling. A recent application of this same principle is found in the *iceless refrigerator.* A wood frame of the desired size is covered with galvanized-iron or copper wire netting. The sides are then covered with Canton flannel, which extends into a pan of water set on top of the refrigerator. By capillary action water is carried over the walls of the pan, and gravity then carries it down through the meshes of the cotton so that the entire cloth is wet. It is well to have pans under the cloth at the bottom to catch any water which has not evaporated. As the cooling effect is due entirely to evaporation, dry air and wind increase the efficiency of the iceless refrigerator. It is of little value in moist and stagnant air. The air inside the refrigerator is always moist, and so molding is favored. The iceless refrigerator cannot satisfactorily replace the ice refrigerator in hot or humid weather, but during spring and fall it may be used with success. It also makes a satisfactory substitute for a refrigerator at a camp where ice cannot readily be obtained.

A cold window box designed on this principle is often useful. A metal pan is fastened to the sill of a north window. A cloth-covered wire frame is set into the pan, which has water in it. A non-conducting cover is placed over the top. Keeping the window open usually helps the draft and promotes cooling.

Artificial cold. The principle underlying artificial production of cold, whether for ice making, cold storage, or any other purpose, on a commercial scale, is simply this. Certain gases are liquefied under pressure. The heat developed during compression and condensation is removed. The pressure is then reduced and the liquid vaporizes. Cold results, because it always requires heat to vaporize a liquid. Heat is further absorbed by the expansion of the gas which results from the vaporization of the liquid.

Liquid ammonia boils and also liquefies at —37° F. at atmospheric pressure (150 pounds per square inch). It requires 2 atmospheres to keep ammonia in a liquid state at 0° F., 7 atmospheres (or 107 pounds per square inch) to keep it liquid at 60° F., and 10 atmospheres (155 pounds per square inch) to keep it liquid at 80° F. If we have liquid ammonia at any pressure above 1 atmosphere and decrease the pressure, the liquid ammonia will change to gas, absorbing heat and lowering the temperature. The degree of temperature possible at any pressure is far below the boiling point for that pressure. Just as alcohol in evaporating may produce a temperature many degrees below its boiling point, so liquid ammonia will, in vaporizing, rapidly produce a temperature lower than —37° F. The evaporation of liquid ammonia in the pipes in

making artificial ice takes place at about 5° F. At this temperature, each gram of ammonia vaporized absorbs 314 calories, and the brine is cooled to about 16° F.

Cold storage. Many foods are produced in abundance only for a short period during the year, but we wish to use these foods over a long period of time. Cold storage makes this possible. In all our large cities cold-storage warehouses are cooled, either by circulating cold

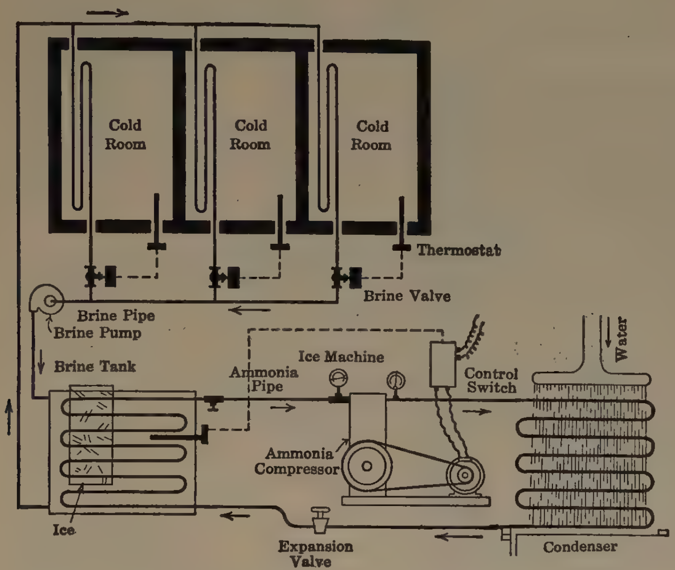


Fig. 177.—Refrigeration plant for cold storage and making ice.

brine in pipes through the rooms where foods are kept, or by having ammonia expansion pipes in the rooms. You frequently see the frost-covered cooling pipes in a fish or meat market.

Quick freezing. Fresh foods, as fruits, fish, and meat, may be frozen, and if kept frozen until time for use, they preserve their quality of freshness. The secret of preserving their natural properties is to freeze them quickly. When water freezes slowly the crystals of ice formed are large; in intense cold, more crystals but finer ones form. In quick freezing the cell walls and tissues of foods are not ruptured as they are in slow freezing. Foods placed in packages are run through refrigerating machines where temperatures of —10° F. or lower are maintained. These foods must be kept at a temperature below freezing during transportation and storage until purchased by the consumer.

Manufacture of artificial ice. The process of manufacturing ice can best be understood by reference to the diagram, Fig. 177. During the compression stroke of the pump, ammonia gas, which fills the cylinder of the pump, is forced into the cooling pipes. By repeated compression strokes the ammonia gas in the cooling pipes reaches sufficient pressure to liquefy. In liquefying, it gives out heat. The spray of water outside the pipes removes this heat. The cooling pipes are connected with coils of pipe, called *expansion pipe,* in a brine tank. The liquid ammonia passes through an expansion valve into the expansion pipe, which is connected to the pump. During the expansion stroke of the pump, a partial vacuum is created inside the cylinder. The ammonia gas rushes from the coiled expansion pipe to the pump. As the pressure in this pipe is decreased, more liquid ammonia vaporizes. Both the changing of the liquid ammonia to a gas and the expansion of the gas absorb heat from the brine, which may be cooled to any desired temperature. Metal cans of pure water are lowered into the brine, which for this purpose is kept at about 16° F. In a large plant hundreds of cans of water are frozen at one time. Each can holds 300 pounds of water and requires about 56 hours to freeze solid.

FIG. 178. — Freon is the safe refrigerant. Under suitable conditions it can produce a temperature of 50° F.

Skating rinks are possible in hot weather by having a series of ammonia expansion pipes a few inches below the surface of the water which, when frozen, is to become the skating surface.

Mechanical household refrigeration. Mechanical refrigeration is very popular. It dispenses with the iceman, it maintains a uniformly low temperature, and it provides a temperature below freezing for making ice and frozen desserts. The underlying principle of most mechanical refrigerators is the same as that of the larger commercial machines for cold storage and ice making, but the refrigerants used are more easily liquefied. Some of the liquid refrigerants that have been used are ethyl chloride, methyl chloride, sulfur dioxide, and butane. These liquids have now been superseded in most makes of refrigerators by a compound known to the chemist as dichlorodifluoromethane, but

whose trade name is Freon. Freon will not burn, is odorless, is not poisonous or irritating if breathed, and has a boiling point 21.7° F. below zero. If by accident it escapes from its enclosure it can do no harm. It seems to be the ideal household refrigerant.

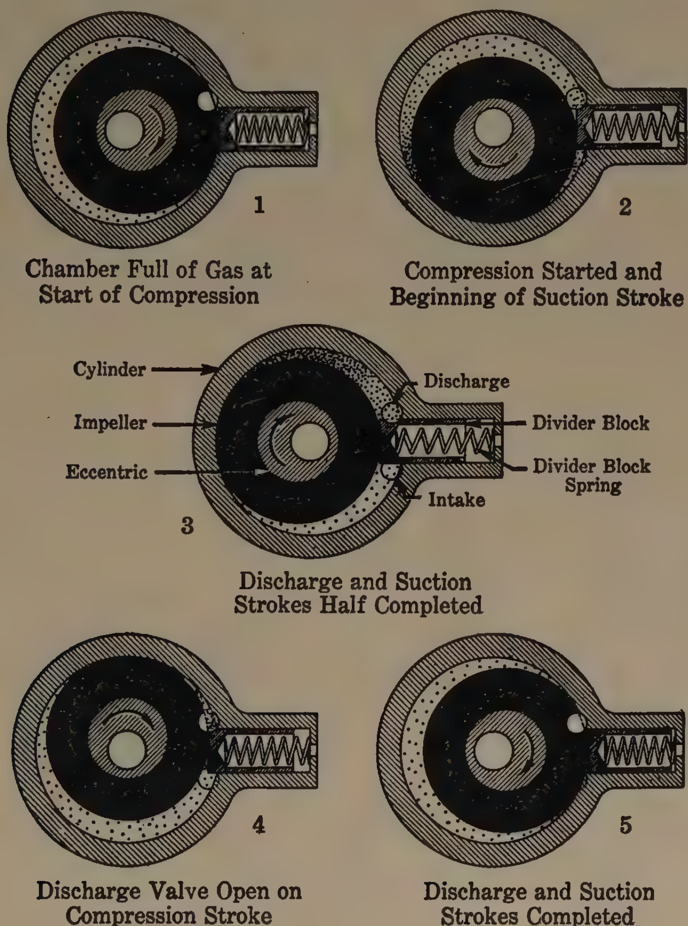


FIG. 179.—Rotary compressor in mechanical refrigerator.

Rotary compressor. The rotary compressor pump has replaced the piston pump of earlier refrigerators. Within a cylindrical chamber a smaller cylinder, called an *impeller,* is rotated by an eccentric. Intake and discharge pipes open to the chamber, but a divider block is always pressed upon the impeller so that no gas can pass across from one chamber to the other (see 3 in Fig. 179). Follow the movement of the impeller from 1 to 5 to see just how the Freon is taken through the

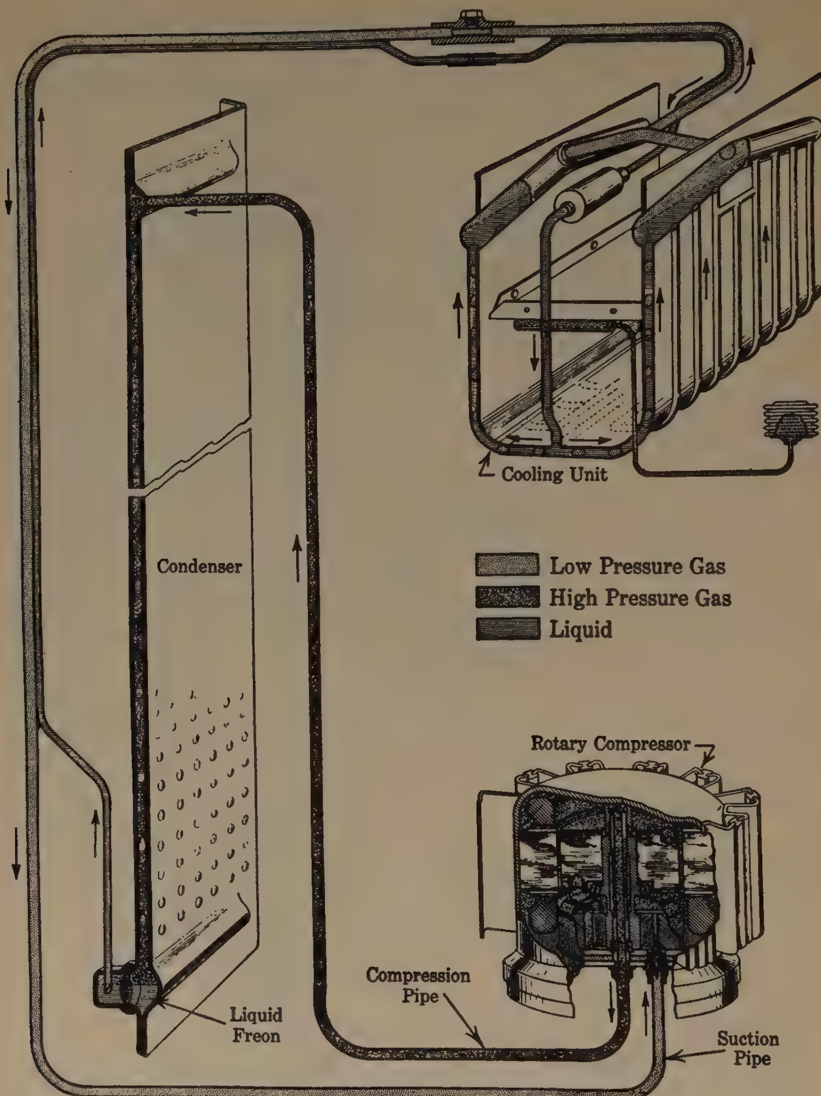


Fig. 180.—Working parts of the mechanical refrigerator.

intake opening and forced out through the discharge opening. The suction pipe is joined to the intake opening and the compression pipe is joined to the discharge opening (see Figs. 179 and 180).

How cold is produced. Three essential parts of the cooling plant are the compressor, the condenser, and the cooling unit. There are connecting pipes as indicated in Fig. 180. Freon gas is pumped or

forced by the compressor into the condenser. The condenser is situated at the back of the refrigerator. It has a large metal surface exposed to the air. Compression heats the gas. Moving air in contact with the condenser takes away the heat. Continued compression causes some of the cooled compressed Freon gas to change to a liquid.

Pressure forces the liquid into the cooling unit. The cooling unit consists of the walls of that part of the refrigerator where the ice cubes are made. Spaces within the walls receive the liquid Freon. A larger pipe connects the cooling unit with the intake or suction side of the compressor. Freon changes from a liquid to a gas in the cooling unit, and the gas expands. Both the changing to a gas and the expansion of the gas are heat-absorbing processes. They produce the cooling effect. Water or foods placed within the cooling unit may be frozen. Circulating air keeps all parts of the refrigerator cold.

The gas refrigerator. The basic principle of using a tiny gas flame as the motive power for the gas refrigerator was discovered in 1922 by Swedish scientists. There is no machinery to wear out, and no noise is made. It utilizes the old principles: condensation liberates heat, and vaporization absorbs heat. The heat produced by condensation is removed by natural moving air currents outside the refrigerator chamber, and the vaporization takes place in the expansion chamber or cooling unit within the refrigerator. The complete process is too technical for description here. It is not as simple as that of the mechanical type of refrigerators, but its results are just as good.

Defrosting. In all home mechanical and gas refrigerators the extreme cold of the cooling unit causes moisture from foods and from air entering the refrigerator when door is opened to coat the cooling unit. This "frost" contains some undesirable compounds, oil and grease, which would give a taste to food or oily appearance to water. It also is a partial insulator and reduces the effective cooling of the air, and so it should be removed. The cooling unit is "defrosted" by various methods. If the cooling mechanism is shut off for a time, the unit will warm until the ice coating comes off. The removal of ice may be hastened by placing the ice-cube trays filled with hot water back in the cooling unit.

Air conditioned refrigerators. In order to humidify the air inside the refrigerator and prevent that dryness that takes moisture from the foods, a "cold plate" is used. A metal plate on one side of the chamber has the vaporizing refrigerant behind it. This does not produce a temperature low enough to freeze water. However, it cools the air and moisture collects upon it. Circulating air will not be dried out as it would if it came in contact with ice or with the cooling unit that is

used for freezing. The freezing unit for ice cubes and frozen desserts may be separated entirely from the food compartment. When this is done no defrosting is necessary. A fan for slowly circulating and filtering the air in the food compartment can be found in some models.

SUMMARY

1. Evaporation of water from porous surfaces has long been practiced for cooling.

2. For many years ice was shipped from northern to southern regions, but today artificial ice is manufactured even where natural ice can be obtained.

3. It requires 80 calories of heat to melt 1 gram of ice at 0° C., and 144 B.t.u. to melt 1 pound at 32° F.

4. Many substances change from a solid to a liquid at a definite temperature, called the melting point. The melting point of ice is 0° C. and 32° F. Liquids solidify at the melting points if heat is withdrawn.

5. Usually a change in volume accompanies a change in state. Many substances, as water, iron, and type metal, expand upon solidifying.

6. The temperature of the water at the bottom of a pond is 39° F. when the pond is covered with ice.

7. The freezing mixture, salt and ice, produces a low temperature because heat is absorbed when ice melts and when salt dissolves in water. The process is aided by the production of a brine which has a freezing point below that of water.

8. The refrigerator has an insulated space in which air cooled by means of ice may circulate about foods and remove heat from them.

9. A refrigerator well filled with ice and food gives the highest efficiency. Ice must melt in a refrigerator or it cannot absorb heat.

10. Condensation of moisture from the air upon the surface of the ice is a large source of heat which melts the ice. Cooling the air is another source.

11. Artificial cold results from the vaporization of liquid ammonia and subsequent expansion of the gas. Powerful pumps are used to compress the ammonia gas in order to reduce it to a liquid state again.

12. Artificial ice is made by freezing cans of water in brine cooled by means of coils of pipes in which ammonia is vaporizing and expanding.

13. Large warehouses are cooled artificially for food storage.

14. By freezing fresh foods quickly at extremely low temperatures, much of their original quality of freshness is retained.

15. Mechanical household refrigerators are cooled by removing heat from compressed Freon and then allowing it to evaporate and expand, when it absorbs heat.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Report on a trip to see ice harvesting, to an artificial ice plant, or to a cold-storage warehouse.
2. Foods and cold storage.
3. Compare the efficiency of two refrigerators by actual test.
4. Make an iceless refrigerator.
5. Use of mechanical refrigerator for frozen foods.

CHAPTER XV

ELECTRICITY IN EVERYDAY LIFE

Many discoveries in science appear to be of no importance at the time they are made. You read about them, but say, "very interesting, but what are they good for?" If you do not see any practical use for them you consider them of little or no value. These beginnings of knowledge about new things or properties of old things have a way of growing or developing into something quite worth while in time. When the ancient Greeks discovered that amber rubbed with cloth acquired properties of attracting light objects to it, they were astonished and interested, but they considered it merely a toy to play with. In the course of a few hundred years electricity was slowly developing; more and more facts concerning it were discovered. But until within less than a hundred years it did not have any important commercial value. What would those early Greek experimenters think if they could step into our world of today and see the work that electricity does for us!

Our use of electricity. Few of us pass a day without some experience with electricity and magnetism. We press a button at the door of a friend, and someone opens the door; we lift the receiver of the telephone and talk to a distant person; at a turn of a switch we may flood the house with light or heat the oven for baking; we turn on the radio and listen to programs produced in distant lands. The electric clock gives us accurate time. Electric motors do much of our work: for example, sweeping, washing, sawing wood, cutting ensilage, "cranking" the automobile, and milking the cows. In case of fire, electricity takes the message that calls the fire engines. We are X-rayed by the physician or dentist. With all this power it is little wonder that electricity may also do harm. It may start a conflagration or take human life. Not only is it used in the electrocution of criminals, but it causes many accidental deaths. Living as we do in this "Age of Electricity" it is essential that we have some knowledge of electricity and its properties in order to make safe and effective use of it.

Kinds of electricity. Thales, one of the "seven wise men" of early Greece, is credited with the discovery that amber when rubbed with silk acquired a new property — that of attracting other light objects to it. The Greek word for amber is **elektron.** Over three hundred years ago

William Gilbert, physician to Queen Elizabeth, gave the name **electricity** to this new something that the amber or glass acquired when rubbed.

If a glass rod, rubbed with silk, is suspended by a thread so it can turn horizontally and another glass rod similarly rubbed is brought

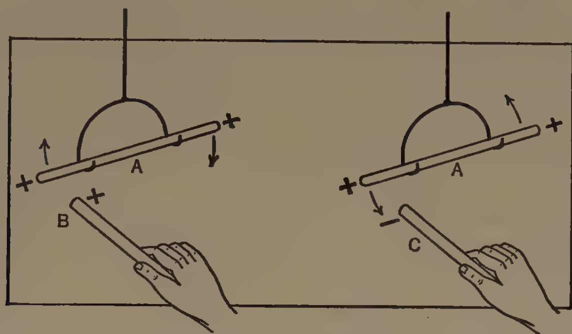


FIG. 181.—Like electrical charges repel; unlike charges attract.

near it, the two rods will repel each other. But if a rod of hard rubber rubbed with fur is brought near it, the two rods will be attracted. It is thus evident that there are two kinds of electricity. Like kinds repel, and unlike kinds attract, each other. By definition, that electric charge on glass when rubbed with silk is **positive** (+). Everything with a charge unlike that on the glass is **negative** (—). Hard rubber when rubbed with fur has a negative charge of electricity. William Gilbert invented an instrument called the **electroscope**, by which bodies could be tested to see whether they had any charge and if they did to tell whether it was positive or negative.

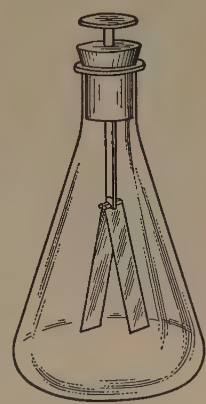


FIG. 182.—The electroscope.

How bodies are charged. Every neutral body is believed to be made of atoms which are in turn composed of still smaller particles. A nucleus at the center of the atom contains an excess of positive particles called **protons** (+). Outside of the nucleus are negative particles called **electrons** (—). Protons are about 1800 times as heavy as electrons. They are in the center of the atom and cannot be removed easily. All neutral bodies have equal numbers of electrons and protons. Some of the electrons may be removed from one body, temporarily, and taken up by another body. Bodies are charged by **friction** as follows. When silk is rubbed over glass, some electrons are

lost by the glass and gained by the silk. This makes the glass positive, since it now has an excess of protons, and the silk is negative because it has an excess of electrons. When rubber is rubbed with fur, electrons go from the fur to the rubber, making the rubber negative and the fur positive. Always, when electricity is produced, just as much positive as negative is produced.

Electrons repel electrons. Protons repel protons. Electrons and protons attract each other. When a negative body touches a neutral body electrons are pushed over into the neutral body, making it negative. When a positive body touches a neutral body it attracts electrons from it and makes it positive. This is electrifying a body by **conduction** or **contact.**

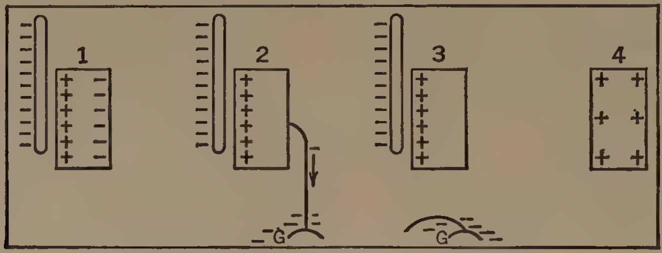


FIG. 183. — Electrifying a tin can by induction.

A third way to charge a body with electricity is by **induction.** When a negative body is brought near a neutral body it repels electrons from the side near it to the more distant side, but if the body is touched with the finger the body is "grounded" and the electrons pass off to the ground. Now remove the finger, and the electrons cannot get back. Remove the negative body used to produce the charge, and the body that was neutral now has a positive charge. If you start with a positively charged body, electrons will be drawn up from the ground and a negative charge will result. The charge produced by induction is always of a kind opposite to that of the charging body.

Conductors and insulators. On a cold, dry day in winter, scuffing the feet over a woolen carpet will charge you with electricity. The wool does not conduct the charge from you, but if you touch a piece of metal or another person the electricity will leave you and as it does so will produce a spark. The bodies you electrify by friction are insulators — bodies through which electrons cannot easily pass. For hundreds of years it was believed that metals could not be electrified by friction, but when someone put a metal on an insulated handle instead of holding it in the hand it was found that it could easily be

electrified. Common things may be classified according to their ability to carry electrons as good conductors, poor conductors, and insulators.

TABLE XVIII

Conductors and Insulators

Conductors	Poor Conductors	Insulators	
Metals	Wood	Amber	Glass
Water	Trees	Sulfur	Porcelain
Human body	Cotton	Mica	Sealing wax
Wet wood		Quartz	Rubber
Graphite		Wool	Silk
		Air	Asbestos

Static electricity. Electricity at rest on a body is called **static electricity** in contrast to current electricity, which is due to a continual flow of electrons. Clouds become charged with electricity by the friction between air and raindrops. Clouds may induce an opposite charge in the earth. When the electric charge is under great pressure it may overcome the resistance of the air and discharge electrons from one body to the other. Such a discharge is the well-known lightning. Buildings, trees, poles, or any object reaching up above the ground is charged like the earth and is a possible target for lightning. Lightning rods that reach deep into the moist earth and extend above a building are a protection to the building because they discharge much of the electricity silently and relieve the tension enough to prevent a stroke of lightning.

If two conductors separated by an insulator are given opposite charges, they will attract each other through the glass. The Leyden jar is a device of this kind for storing up static charges. The two charges can neutralize each other only if a conductor touching one of them reduces the air gap between the two until a spark can pass. Huge machines have been made for experimental use by which static charges having an electrical pressure of more than a million volts have been produced. When two insulated bodies having opposite static charges are connected by a metal, electrons flow from the negative to the positive body. This flow of electrons is an **electric current.**

Production of current electricity. Just as, in our water-supply system, water flows through the pipes only when there is pressure behind it forcing it along, so an electric current flows through a conductor only when the electrical pressure forces the charge along,

thereby producing a current. If a small current of electricity is required, as in ringing a doorbell, the common **dry cell** is used. To start an automobile a stronger current is needed; this is supplied by a **storage battery.** For our street and house lights, higher pressures and more current are required, and electrical machines called **generators** or dynamos are employed. Millions of dollars are invested in plants which produce current electricity for commercial use. Thousands of generators all over the country make the electric current for electric trains and trolleys, for motor-driven machinery, for our electric lighting and heating devices, and for the majority of our telegraph and telephone lines. Current electricity produced by means of cells or batteries is obtained at the expense of chemical energy. Electrical energy from generators comes directly from mechanical energy. The source of the mechanical energy is usually falling water or the steam engine which gets its energy from the burning of coal.

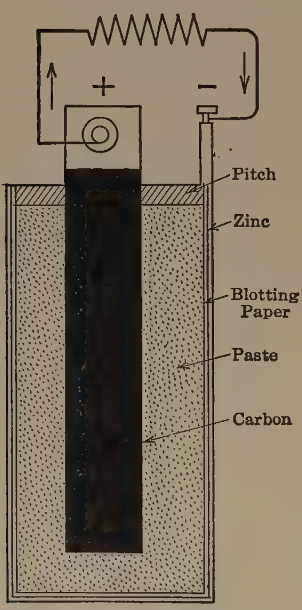


FIG. 184. — Vertical section of dry cell.

The dry cell. The electric cell most used is the so-called *dry cell.* The essential parts of the dry cell are *two plates,* usually zinc and carbon, and an *electrolyte.* Many different chemicals act as electrolytes, but ammonium chloride is the most common substance. The zinc is in the form of a metal can which holds the other materials. The space between the carbon and zinc is filled with a paste which contains the electrolyte. The composition of the paste in a typical dry cell is as follows:

Ammonium chloride	1 part
Chloride of zinc	1 part
Manganese dioxide	1 part
Granulated carbon	1 part
Plaster of Paris	3 parts
Flour	1 part
Water	2 parts

The manganese dioxide improves the action of the cell by chemically removing hydrogen, which tends to decrease the current by collecting on the carbon. The moisture is retained in the cell by sealing the top surface with an impervious layer of pitch. The structure of the cell is shown in the section diagram, Fig. 184. Each cell is insulated by a pasteboard container. The carbon pole is called the **positive** (+) **pole,** and the zinc, the **negative** (—) **pole.** As the result of an arbi-

trary agreement, the current in the outside circuit, or wires connecting the carbon and zinc pole, is considered as flowing from the carbon to the zinc.

Since the electricity results from chemical action in the cell, a definite amount of electricity is available from each cell, depending upon the materials used and the size of the cell.

Resistance to an electric current. A given difference of potential or electrical pressure causes a definite amount of current to flow through a given copper wire, but, if the length or the diameter of the wire is changed, a different amount of current will flow. This is due to the fact that all conductors offer *resistance* to the flow of current. A long wire offers more resistance than a short one of the same sort. A fine wire gives more resistance for the same length than a coarse one. The material also affects the current flow. Iron offers much greater resistance to an electric current than copper of the same length and diameter. Water will be discharged from a tank more quickly through a short hose than through a long one because of the greater friction of the long hose. It will also be discharged more quickly, that is, there will be a larger current of water, through a pipe of large diameter than through one of small diameter. Do you see how similar this is to the flow of electricity through a wire?

Three fundamental electrical units. You probably see that the current which passes in any electrical circuit depends upon the resistance. It also depends upon the difference of potential or electrical pressure. But how do we measure current, difference of potential, and resistance? There must be units for the measurements of electrical quantities, just as there are units for weight, distance, and time.

The unit of current strength is the **ampere**; it is the amount of current which deposits 0.001118 gram of silver per second when passed through a cell containing a silver salt.

The unit of resistance is the **ohm**; it is the amount of electrical resistance offered by a uniform column of mercury 106.3 centimeters long and 1 square millimeter in cross section, at 0° C.

The unit of electrical pressure is the **volt**; it is the difference in potential between the ends of a wire having a resistance of 1 ohm when 1 ampere of current is passing.

These three units commemorate the names of three famous scientists: Ampère, a Frenchman; Ohm, a German; and Volta, an Italian. Ohm found out the relation which exists among these units and stated it in the form of a law, which has been named for him.

Ohm's Law: *The current in a given circuit varies directly as the voltage and inversely as the resistance.*

This law is conveniently expressed by the equation:

$$\text{Current (in amperes)} = \frac{\text{pressure (in volts)}}{\text{resistance (in ohms)}}, \text{ or } I = \frac{E}{R}$$

The unit of electric power. When we use 1 ampere at a pressure of 1 volt, we consume 1 *unit of electrical power,* namely, 1 **watt.**

$$\text{Amperes} \times \text{volts} = \text{watts}$$

Since the watt is so small, the **kilowatt,** equivalent to 1000 watts, is more commonly used. A watt continued for 1 hour gives **1 watt-hour,** which is the unit of *electrical work or energy.* A **kilowatt-hour** is equivalent to the energy of 1000 watts continued 1 hour. One horsepower equals 746 watts.

The use of dry cells. The e.m.f. of a dry cell is independent of the size of plates or their distance apart, being dependent only upon the materials used. The amount of current which the cell will furnish, however, depends upon the resistance of the cell as well as upon the resistance in the outside circuit. The larger the plates and the nearer they are together, the less the internal resistance. Decreasing the internal resistance tends to increase the current. The common dry cell, when new, gives an e.m.f. of about 1.5 volts and more than 25 amperes,

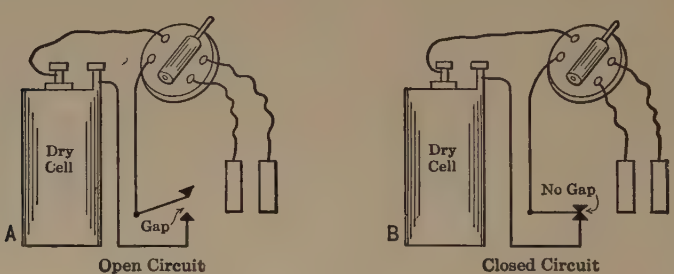


FIG. 185. — Open and closed circuits.

if its terminals are joined by a conductor of negligible resistance. During use, the chemicals attack the zinc, and gradually both zinc and chemicals are consumed. Dry cells are successful for *open-circuit* work, that is, for periodic or intermittent use. If the circuit is closed for a long time, the current diminishes but will recover after the cell stands for a time on open circuit.

Closing a circuit. Electricity, at the pressures commonly employed, may be prevented from flowing by separating any two parts of the conducting wire in the circuit by a very narrow air gap; but, if the air

gap is removed by bringing the metal surfaces together, current will flow. There are many different devices for opening and closing an electric circuit. Three common types of circuit closers are the **push button,** which you press to ring the doorbell; the **knife switch,** to connect the house wires to the outside line wires; and the **socket switch,** to control individual lights. The button switch can safely carry only a fraction of an ampere and should not be used with a voltage above 15. Wall switches for electric lights are of heavier metal than the socket switches and usually control several lamps. The key of a telegraph sounder is a circuit closer, as is also the telephone plug and jack.

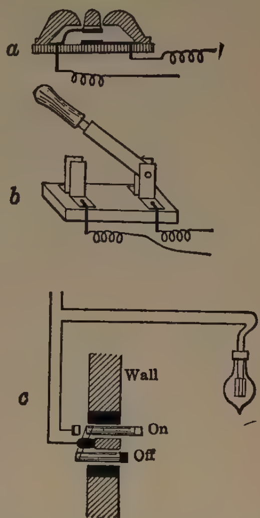


FIG. 186. — Circuit closers. (*a*) Push button. (*b*) Knife switch. (*c*) Wall switch.

Insulated wire. When it is desired to use electricity at a distance from its source, it is generally led there by a metal conductor. In order that the electricity may not "leak" off on the way, the metal conductor — usually a wire — is covered with an insulating material. Common insulators for this purpose are: rubber, silk, cotton, paraffin, and wax-impregnated fabric. Insulation not only prevents loss of electricity, but also lessens the hazard of fire and safeguards persons from accidental shock. When a house is wired, the insulated wires which pass under floors and within walls are enclosed in a flexible sheath. One type is the BX-cable shown in Fig. 187. The service-entrance cable connecting your house to the power line must be very strong and well insulated. One type of such cable is shown.

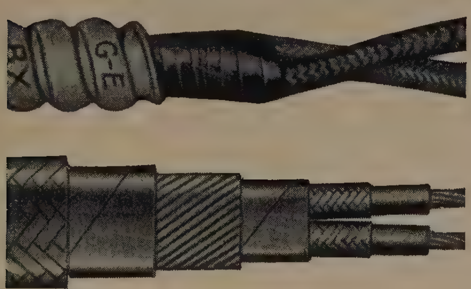


FIG. 187. — BX cable above. Service-entrance cable below. Both are strong and well insulated.

PROBLEMS

1. How many amperes of current will be furnished through a wire having a resistance of 1.2 ohms, by a pressure of 10 volts?
2. An incandescent lamp connected across 110-volt mains takes a current of

0.25 ampere. What is the resistance of the lamp filament when the lamp is lighted?

3. How many watts does the lamp of Problem 2 consume?

4. At the local rate for electrical power, what will be the cost of operating the lamp of Problem 2 for 30 days at an average burning of 4 hours per day?

Different effects of an electric current. Many different results can be obtained from an electric current. In the household iron, the current produces heat; and in the incandescent lamp, light. The chemical effect of an electric current is utilized in copper, silver, nickel, and chromium plating, and in the production of a large number of chemical substances. Every wire conducting electricity is surrounded by a *magnetic field,* which disappears when the current is cut off. Advantage is taken of the magnetic effect of a current to produce motion in the electric motor. Magnetism is of importance not merely because it accompanies an electric current and finds application in many electric devices, but also because it is a contributing factor in producing most of our commercial electricity — that coming from the generator. The magnetism produced by an electric current has all the properties of that produced by ordinary magnets.

Magnetic substances. Magnets attract iron, steel, cobalt, nickel, and some other elements. Iron is the chief constituent of steel, and of all elements it is most strongly attracted by a magnet. Substances

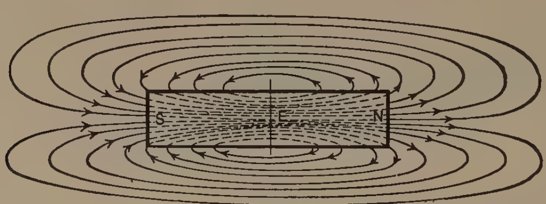


FIG. 188. — Lines of force in the magnetic field which surrounds every magnet.

which are attracted to a magnet or which can become magnets are *magnetic substances.* Those which cannot be magnetized and are not attracted are *non-magnetic substances.*

Magnetic poles. The magnetic effect is strongest near the ends of the magnet. These regions are known as the *poles.* The place midway between the poles is often referred to as the *magnetic equator.* Either pole of a magnet attracts magnetic bodies. A magnet suspended so that it is free to turn in a horizontal plane comes to rest in a north and south line. That end which is toward the north is called the **north pole**

(north-seeking), and the opposite end, the **south pole.** *Unlike poles* of magnets *attract* each other; *like poles repel* each other.

Magnetic field. That portion of space about a magnet in which its attractive force can be detected is called the *magnetic field.* This field is represented as being filled with **lines of force,** whose direction is from the N-pole to the S-pole outside the magnet, and from the south to the north within the magnet. The direction may be tested with a compass needle, since the N-pole will point in the direction that the line of force is assumed to take. Iron is a better conductor of lines of force than air; therefore, a piece of iron placed within the magnetic field distorts the field. Likewise, the iron thus placed exhibits magnetic properties,

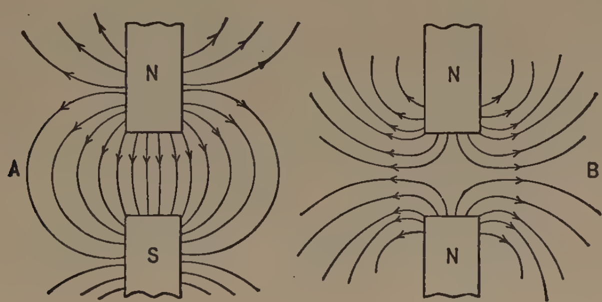


FIG. 189. — (*A*) Magnetic field about two unlike poles. (*B*) Magnetic field about two like poles.

since it has lines of force entering one end and leaving the other end, as all magnets do. This process of magnetizing iron is known as **magnetic induction.**

Theory of magnetism. When a bar magnet is broken into two parts, each part appears to be a complete magnet, each with a north and a south pole. If each part is broken and then each of the subsequent parts is broken, each small piece is also a complete magnet. In our imagination we may carry this division beyond the possibility of actual experiment, to the smallest physical unit, the molecule. It is believed that each molecule of iron is a magnet, and that, when any magnetic force acts upon a bar of iron with sufficient strength to cause many of these molecules to arrange themselves with axes parallel to each other and N-poles pointing in the same direction, the bar will exhibit magnetic properties. In an unmagnetized bar of iron, the molecules are arranged in groups so that the lines of force are kept within the bar. It is only when the lines of force go outside the bar and create a magnetic field that the bar exhibits the property of magnetism.

The earth's magnetism. The compass is a magnet suspended so that it turns freely in a horizontal plane. The earth's magnetism is sufficiently strong to make one end of the compass needle point toward the

earth's nearest magnetic pole. The value of a compass lies in the fact that with it you can determine directions when all other means fail. It is thus of great importance to navigators, explorers, and surveyors. In most places the compass needle does not point exactly toward the geographic north. This is because the magnetic pole is some thousand miles distant from the geographic pole. The deviation of the compass needle from the true north is called the **angle of declination.** You can

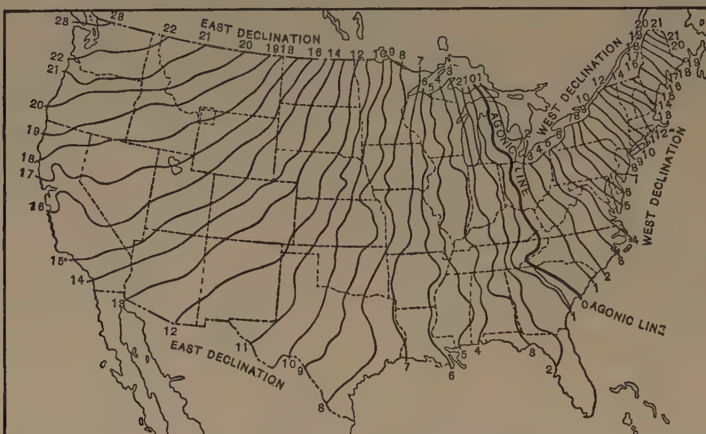


FIG. 190. — Map of magnetic declination.

learn from a surveyor how to correct the compass reading for your locality, or you can tell approximately by consulting the map in Fig. 190. The compass needle points toward the geographic pole on the agonic line.

Electromagnets. We have already referred to the fact that every electric current is accompanied by a magnetic field. This may be strikingly demonstrated by bringing a wire carrying a direct current near and parallel to a compass needle. By observing the way the needle is deflected, the direction of the lines of force about the wire may easily be determined. The **right-hand rule** will help us to remember the relation of current direction and lines of force. It is this:

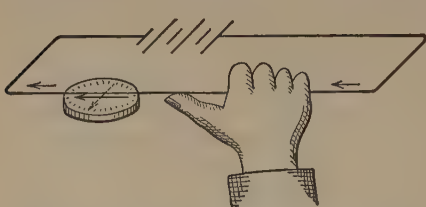


FIG. 191. — The right-hand rule for direction of lines of force.

Grasp the wire with the right hand so that the thumb points in the direction that the current flows in the wire, then the fingers are pointing in the direction of the lines of force about the wire.

When a loop of wire carries a current, lines of force enter one side and leave the other; thus, each loop has the properties of a magnet with north and south poles. Many loops close together in a coil make a **solenoid.** A solenoid with a soft-iron core is an **electromagnet.** The iron core makes a better path for the lines of force, so that they are concentrated inside the coil, and thus make much stronger magnetic poles than could be obtained with the solenoid alone. Here is another right-hand rule for the relation between current direction and polarity of an electromagnet:

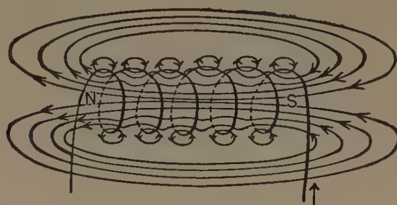


FIG. 192. — Magnetic field around a solenoid.

If an electromagnet is grasped with the right hand, so that the fingers take the direction of the current, the thumb will point toward the north pole of the magnet.

Electromagnets are of the greatest importance, not only in producing electricity, but also in utilizing it, for without them many of our most valuable electrical devices would not exist.

Electromagnetic induction. We have just learned that, when a current flows through a conductor, magnetic lines of force are set up in the surrounding space. Since an electric current produces a magnetic field, we might expect that a magnetic field would produce an electric current, and it can easily be demonstrated that moving magnetic lines of force may produce a current, which is called an **induced current.**

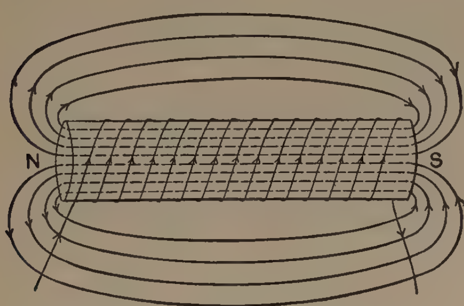


FIG. 193. — Magnetic field around an electromagnet.

An induced electric current results whenever lines of magnetic force are "cut" by a closed coil of wire.

In other words, any relative motion between lines of magnetic force and a closed coil which changes the number of lines through the coil produces an electric current. Faraday was the first to discover this fact. This was in 1831, and now, more than one hundred years later, we find application of this principle in all our electric power plants, which make electricity for light and power.

Suppose that we have a closed circular conductor A, Fig. 194, and

move the north pole of a magnet toward it. A current will result in the conductor, flowing as indicated by the arrow. When the north pole of the magnet is moved in the opposite direction, the current in the conductor is in the reverse direction, as shown in *B*. Electricity would be produced in just the same way if the loop of wire were moved instead of the magnets. If a closed coil of wire *C*, Fig. 194, is rotated between the poles of a horseshoe magnet, a current is generated which can be detected by means of a galvanometer *G*.

Thus far, we have spoken of a *closed* loop or circuit and of an electric *current*. But we know that an electric current is set up in a conductor

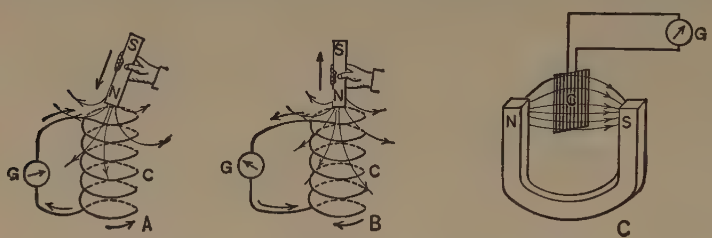


Fig. 194.— An induced current results from relative motion between a closed loop or coil of wire and magnetic lines of force.

by producing *electric pressure*. A more precise way of stating the above would therefore be to say that any conductor moving across (not parallel to) lines of magnetic force *will generate an electromotive force.*

Electromagnetic induction makes electricity the important factor that it is, in our life of today. Thomas Edison was a pioneer in developing the machine which would produce electricity on a commercial scale. The machine is called a *generator* or a *dynamo*. It converts mechanical energy into electrical energy. A simple generator has two magnetic poles, between which rotates a coil of wire called the armature. The ends of this armature wire are connected by means of brushes to the outside circuit. Its essential elements are therefore a magnetic field and a moving coil.

How electric current is produced by a generator. Let us try to understand what happens when a single loop of wire is rotated between the poles of a magnet, for if we understand this we shall have a mental picture of what goes on in the large generators in which hundreds of loops of wire are duplicating the action of this single loop. Suppose the loop of wire in Fig. 195, diagram 1, to be rotated in a clockwise direction of the axis xy. As the side AB moves down across the lines of magnetic force, an e.m.f. is induced in it in the direction shown in diagram 2. At the same time, an e.m.f. is produced in the side CD in the

same direction about the loop as that in *AB*. During the first half rotation, the induced e.m.f. is in the direction *ABCD*. During the second half rotation, it is in the direction *DCBA*, or just the reverse of the first e.m.f., and so on continuously, the induced e.m.f. alternating every half turn.

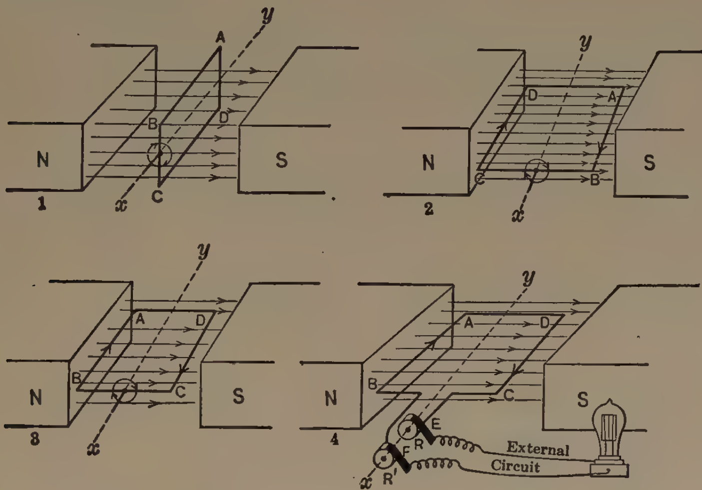


FIG. 195.—Principle of current production in a generator.

How current is taken from the generator. In order to make use of the e.m.f. generated in the rotating coils, or **armature**, of a generator, there must be some way of connecting the coils to an outside circuit. The ends of each loop of wire may be joined to separate metal rings. These rings rotate with the loop. Carbon or metal **brushes** rest on the rings and are connected with the wires of the external circuit (Part 4, Fig. 195). Since one brush is always in contact with the same end of the wire loop, the current taken off will be of the same character as the e.m.f. generated in the loop, namely, an **alternating current**. Collecting rings are always used on alternating-current generators.

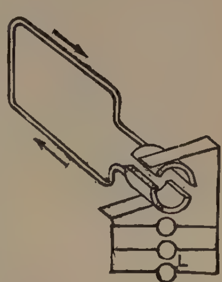


FIG. 196.—A split-ring or segmented commutator.

When a **direct current** is desired, a **split-ring commutator** is used. The ends of the loop are joined to the two parts of the divided ring. The brushes are set opposite each other and come into contact alternately with the two ends of the loop. If the brushes are so placed that contact changes from one section of the ring to the other just as the

e.m.f. reverses, then one brush will always be positive and the other negative. Current will always flow *out* from one brush and *in* at the other, as in Fig. 196; thus, although an alternating e.m.f. is generated in the loop, only a direct current passes through the external circuit. Direct-current generators always have the split-ring commutator.

Meaning of "60-cycle A.C." In the loop of wire described in the previous paragraphs, the e.m.f. increases as the wire passes through the first quarter of a revolution, that is, from the vertical position to the horizontal, and it decreases during the next quarter turn. During the third quarter turn, an electromotive force in the opposite direction is increasing; this decreases during the last quarter turn. Each wire that describes a circle of 360 degrees in passing the two opposite poles of a magnet has an e.m.f. in one direction built up to a maximum; this decreases to zero and is followed by an e.m.f. *in the opposite direction,* which comes to a maximum and then decreases to zero. All this occurs

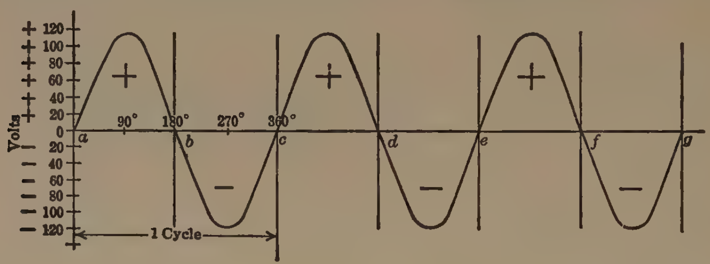


FIG. 197. — Cycles of an alternating current.

during each revolution for every wire rotated. In the graph, Fig. 197, the curve above the horizontal line represents positive e.m.f. A complete cycle is represented by the curve *a* to *c*. Three cycles are represented from *a* to *g*. Suppose the time required for these three cycles to be $\frac{1}{20}$ second; then there would be 60 cycles a second. There are 60 positive impulses and 60 negative impulses a second. Where the curve crosses the horizontal line, there is no voltage in the wire, but this period is of such small duration that we do not detect it. A 25-cycle alternating current, sometimes used in arc lamps, gives a noticeable flicker, though an incandescent lamp appears to give a steady light. The common alternating current used for lighting, known as the "60-cycle A.C.," has 7200 alternations per minute; that is, the direction of the current throughout the entire length of the circuit changes 7200 times a minute.

From the generator to the lamp. Electrical energy must be distributed without injury to persons or property and, as far as possible,

without loss. It has been found that current can be carried at high pressure with little line loss, but greater care must be taken to secure proper insulation for the high voltage. Dangers of fire, shock, and leakage are largely removed by means of insulators. Electricity carried at high pressure and low current heats the conductor less than that carried at low pressure and high current. Consequently, electricity is usually carried in the line wires at a higher pressure than that used in the home. Electricity is transformed from low to high, or high to low, pressure, by a device called a **transformer.** This can be used only with an alternating current.

Transformers. The transformer in principle is an induction machine. There are two coils of wire with an iron core in common. One coil, the *primary,* has an electric current from the a-c. generator. Each current impulse builds up a magnetic field, which *induces* a current in the other, or *secondary,* coil. Suppose that we have a primary coil of 10 turns of wire and a secondary coil of 100 turns. If a current of 5 amperes at 110 volts is brought to the primary coil, we shall have in the secondary 0.5 ampere and 1100 volts. The voltage increases and the current decreases in the ratio of the turns of wire in the primary coil to the turns in the secondary coil. If the primary coil had 100 turns and the secondary coil 10 turns, we should have, for the above case, 50 amperes and 11 volts in the secondary.

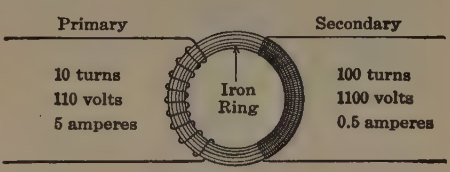


Fig. 198. — A simple "step-up" transformer.

Electricity for light and power, which is used many miles from the generating plant, has its voltage raised by a **step-up transformer,** is carried over the line wires at high tension (pressure), and is reduced by a **step-down transformer** just before it is utilized in motors or for electric lights. Transformers with several secondary coils are made so that different voltages may be secured for such service as electric doorbells and electric toys.

Dangers from electricity. A large number of fires are laid to electricity, and not without good reason, for electrical energy is easily converted into intense heat. When the insulation has worn off an electrical fixture wire, as, for example, a lamp cord, the two bare wires may come together. If they do, sufficient heat to set many materials on fire is produced in an instant. Should a wire be broken and then moved so as to close the circuit loosely, heat and possibly fire will result. Heating devices left uncared for are frequent causes of disastrous fires.

Bodily harm from electricity occurs more frequently than is necessary. This is because of neglect to keep the wire insulation in good condition, and of carelessness about "taking a chance." The resistance of the skin varies with its dryness, being decreased by moisture or greasiness; it also varies with the area which is in contact with an electric conductor. A bare wire carrying our ordinary lighting current at 110 volts or 220 volts pressure may possibly be handled safely if the skin which the wire touches is dry or if the person's shoes, by which current leaves, are dry. But let the hand be wet with water or with perspiration, or let the person stand on a damp floor or ground, and enough current may pass through the heart to paralyze it, and cause instant death. Most fatalities from industrial currents come from those of 500 volts to 5000 volts pressure. Curiously enough, people who have received shocks from 10,000 volts have lived.

Fig. 199. — This illustrates how many fatal electric shocks have been received.

The external metal of lighting fixtures may come into contact with a wire whose insulation is worn off. A person standing on a carpet may touch the fixture and feel nothing, or at most only a slight shock. But if the person were in water in the bath or were to touch a water faucet with one hand and the lighting fixture with the other, the shock received might cause death. Higher voltages than 110 are correspondingly more dangerous. No danger results when a comparatively large current flows through the lower part of the trunk alone, but as low a pressure as 65 volts has been known to prove fatal

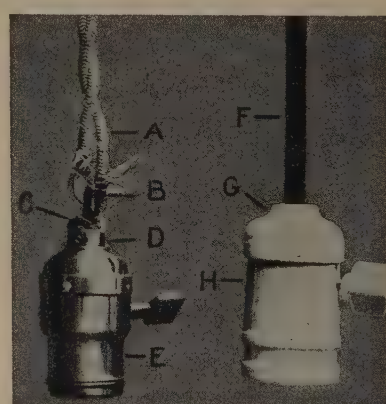


Fig. 200. — At left, an electric hazard. Worn insulation at *B* and the metal socket, *E*. At right, electric safety. Heavy insulation at *F* and a porcelain socket, *H*.

when it passed through the thorax. Birds light on the trolley wire and on the third rail and fly away in safety, because they have made no connection to the earth. You could safely hang from the trolley wire; but if you make connection to establish a path for the current to reach the earth through your body, you are likely to receive a fatal shock. Hence you are cautioned not to touch any fallen wires, for they may at some distance be in contact with the trolley wire. Guy wires and metal posts sometimes carry dangerous voltages. First aid for electric shocks should take the form of artificial respiration, just as for gas asphyxiation and for drowning.

SUMMARY

1. Glass rubbed with silk becomes charged with positive electricity. Hard rubber rubbed with fur is charged negatively.
2. All atoms are composed of positive protons and negative electrons.
3. Neutral bodies have equal numbers of electrons and protons.
4. Three ways to electrify a body are: by friction, by conduction (contact), and by induction.
5. An electroscope is used to detect a charge and to determine the kind of electrical charge. Very delicate electroscopes have leaves of gold or aluminum foil.
6. Matter varies in its ability to conduct electrons and so is classified as conductors, poor conductors, and insulators.
7. An electric current consists of a flow of electrons along a conductor.
8. Generators produce electricity from mechanical energy, to supply our great commercial needs. To a small extent, cells, particularly "dry cells," produce electricity from chemical energy.
9. A dry cell contains two plates, carbon and zinc, separated by a paste containing the active chemical, called the electrolyte. The current is assumed to flow in the outside circuit from the positive carbon to the negative zinc.
10. A charged body is one whose atoms have either an excess of electrons or a deficiency of electrons.
11. All conductors resist the flow of electricity. Fine wire offers more resistance than coarse wire. The resistance increases with the length of the conductor. Resistance varies with the kind of matter, iron having more resistance than copper. Glass and mica are insulators. Water is a poor conductor.
12. Three important electrical units are: the ampere, the unit of current; the ohm, the unit of resistance; and the volt, the unit of

electrical pressure. The unit of electric power is the watt. The relation of these units is expressed in these formulas:

$$I \text{ (amperes)} = \frac{E \text{ (volts)}}{R \text{ (ohms)}}$$

$$W \text{ (watts)} = I \text{ (amperes)} \times E \text{ (volts)}$$

13. Ordinary dry cells give about 1.5 volts and from 15 to 25 amperes, when new. Joining cells in series — unlike poles together — gives a battery whose voltage is the sum of individual cell voltages.

14. An electric circuit is " open " when there is a break or air gap between two parts of the metallic circuit. " Closing a circuit " consists in bridging this gap by means of some conducting material. Common circuit closers are switches and " buttons."

15. Among the important effects of an electric current are: heat, light, chemical action, and mechanical motion.

16. The important magnetic substances are iron and steel. These are attracted strongly by magnets and can be made into powerful magnets. Every magnet has a north and a south pole. Unlike poles attract, and like poles repel, each other.

17. The space about a magnet, filled with magnetic lines of force, is the magnetic field. Lines of force are assumed to have a direction outside the magnet from the north pole to the south pole. A piece of iron in this field becomes magnetized by induction.

18. The earth is a huge magnet. Its magnetic field directs the compass needle. The needle does not in all places point toward the geographic pole, because the magnetic and geographic poles are not in the same place. The angle between the compass direction and true north is the angle of declination.

19. A coil of wire carrying an electric current is called a solenoid; a solenoid with a soft-iron core is an electromagnet.

20. An induced electromotive force results whenever there is relative motion between magnetic lines of force and a conductor. This is the principle underlying the generation of electricity in the dynamo. Alternating-current generators have collecting rings, and direct-current generators have a split-ring commutator for transmitting the current from the armature to the brushes and through them to the outside circuit.

21. In a 60-cycle alternating current there are 60 positive impulses and 60 negative impulses of electricity a second. This means 7200 alternations per minute.

22. A transformer for increasing or decreasing the voltages of an

alternating current consists of two coils of wire upon the same iron core. It is a step-down transformer if the primary coil has more turns of wire than the secondary. It is a step-up transformer if its primary coil has fewer turns of wire than the secondary. Either or both of these types may be used in the distribution of current for electric lights.

23. Defective insulation upon electric-light wires is responsible for many fires. Shock from electric-light wires may produce fatal results. Fixtures which give a shock when they are touched have defective wiring inside and ought to be repaired. First aid in lightning or other electric shocks should take the form of artificial respiration, as for drowning.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. What I saw at the electric power station.
2. Substitutes for the magnetic compass.
3. Determine the energy used by an electric iron.
4. Test the voltages obtained by different connections on a bell-ringing or other step-down transformer.
5. Determine the horsepower of a household motor.

CHAPTER XVI

ELECTRICAL DEVICES IN THE HOME

Three important products of electrical energy in the household are: light, heat, and mechanical energy. There are lamps for lighting, a great variety of devices utilizing the heat that results when electricity passes through a resistant wire, and electromagnetic devices as the bell and motor-driven equipment where motion is required. Sound is mechanical energy, and few are the homes which do not receive broadcasting programs over the radio. For convenient use of the many portable devices now available, several electrical outlets should be installed in every room where these devices may be plugged in. Because of the decrease in cost of electrical energy within recent years, electrical energy is being utilized more than at any earlier time. Its convenience and cleanliness make it the ideal energy for the household.

The house electric circuits. From the power-house generator, the electric current passes through the street lines into a transformer from which it emerges at a pressure considered safe for ordinary household uses. Large copper wires heavily insulated known as " service entrance cable " run between the power line in the street and your house. The main switch, meter, and fuse box are placed together where the current is first brought into the building, though sometimes the meter is on the outside of the building to facilitate its reading each month. From the fuse box, which may also be a distributing box, the different circuits lead off to different parts of the house. Each circuit is designed to supply a certain number of devices. Between the fuse box and outlets the current is conducted by copper wires insulated and protected outside by a flexible sheath. This BX cable is required in many cities since it reduces the danger from fire.

The locations of the lighting fixtures and of the outlets for connecting electrical equipment in a house are of such importance that they should be given careful consideration in planning the house. Many of you have observed, especially if you live in a rented apartment, how poorly lighted some rooms are and how much inconvenience is caused by the lack of outlets for attaching the vacuum cleaner, heating devices, or an electric fan. A large room is lighted by lamps in different parts of the room better than by a single, large lamp in the center. Light from many sources prevents annoying shadows and gives a pleasing,

diffused light which is not so tiring to the eyes. The location of control switches is another important matter to consider in drawing up the house wiring plan.

Light and convenience outlets. The electric outlets for a house should be planned before the house is built. Side-wall lamp outlets, in addition to the outlet for the suspension lamp, will find a use in practically every room. Wall lights also add to the attractiveness of a room.

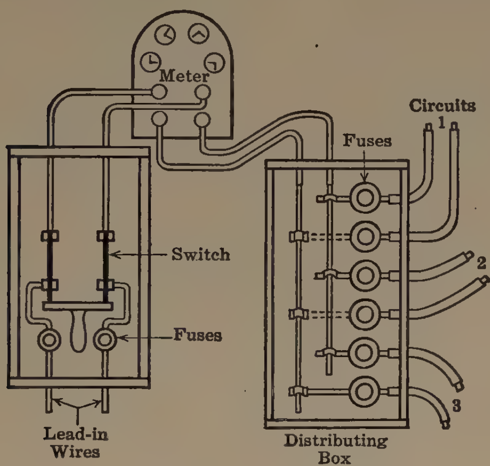


Fig. 201. — Main switch, meter and fuse box.

Baseboard or wall convenience outlets are essential for portable lamps, vacuum cleaners, electric fans, and heaters. It is well to be generous in the installation of these outlets. It costs little to install an extra outlet when building, but costs much more after the building is completed. If there are to be room heaters, hot-water heaters, or electric ranges, heavy charge outlets with heavy wires in the circuits are provided because of the greater electrical energy which will be drawn from them. Figure 202 suggests a practical plan for electrical outlets. It will be observed, by examining the diagram carefully, that the closet light switches are in the door frames and are so arranged that, when the door is opened, the light is automatically turned on, and when the door is closed, it pushes the switch and turns the light off.

Fuses. Fuses have an important place in the electric equipment of the home. They act as a safeguard against harm which might otherwise result from a short circuit. If any piece of metal were accidentally to make connection across bare wires coming from the house circuit, for example, to the heating device, a strong current would flow through

this metal, as it would short-circuit the house wires by cutting out the heating device. This current would be far in excess of what the heating device would allow to pass through the conducting wires. As a result, the wires might become so heated as to cause fire somewhere in a partition of the house; but if there was a fuse of proper size in that circuit

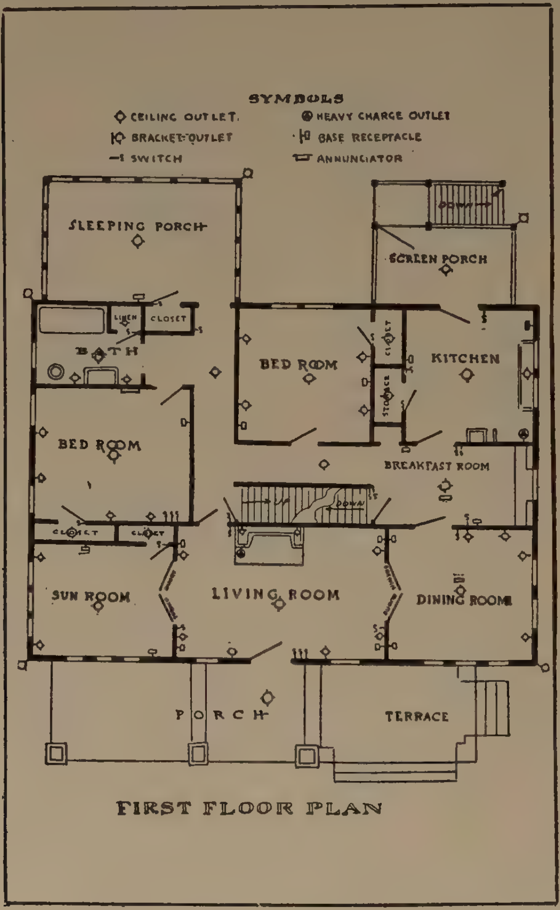


FIG. 202. — Electrical outlets for the first floor.

in the distributing box, such a catastrophe would be averted. The fuse wire, which is an alloy of soft metals of low melting point, is made a part of the house circuit. A current that is great enough to cause fire will melt the fuse wire and open the circuit, so that no more current can flow until a new fuse is put in. It is an easy matter for any careful person to put in a fuse, and every girl should learn how to do it. *Open*

the main switch before putting in a new fuse, in order to avoid all danger of shock. In order to test an old fuse to see if it is good, connect the two metal parts of the fuse as shown in Fig. 204. If the bell rings, the fuse is good.

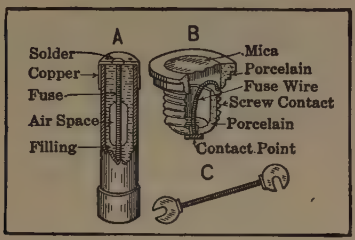


FIG. 203.—Three types of fuses: cartridge, socket, and link.

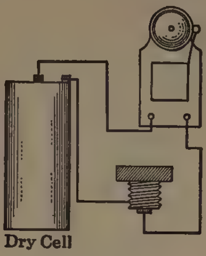


FIG. 204.—How to test a fuse.

Electric lamps. The first extensive use of electricity in the home was for light. The heating effect of electricity passing through a small resistant wire was known long ago by many scientists. It was Edison, however, who finally, in 1879, perfected the carbon-filament incandescent lamp. This was the first electric lamp to become a commercial success. Many improvements have been made until today the electric

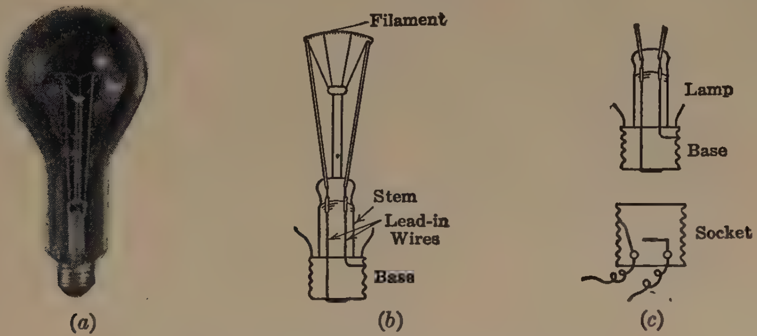


FIG. 205.—Construction of an electric lamp.

lamp is nearly perfect as a source of artificial light. The old carbon lamp gave a yellowish light and took about four times as much electrical energy for the same amount of light as the present tungsten lamp.

Inside the lamp bulb we use today is a straight or a coiled tungsten wire finer than a human hair. This offers great resistance to the current, and heat results. It becomes white hot or incandescent and has a temperature of about 5000° F. Many of our electric lamps are "gas

filled." The bulb is exhausted of air and then filled with argon or nitrogen. The gas in the bulb exerts pressure on the filament and so checks its vaporizing. In this way the filament can be heated to a higher temperature. The higher the temperature, the more electricity is converted into light, and so the greater efficiency obtained.

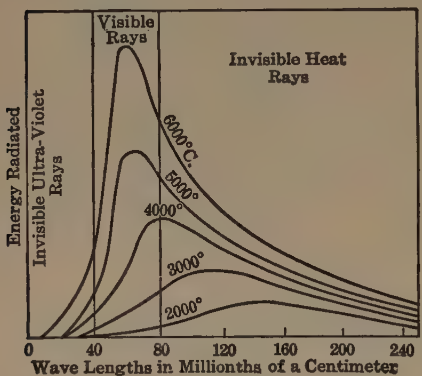


FIG. 206. — The higher the temperature to which a filament can be heated, the greater the ratio of light to heat rays produced.

The strength of the light is indicated by the energy consumption of the lamp in watts. The common lamps run from $7\frac{1}{2}$ to 100 watts. A 25-watt lamp gives about the amount of light of 25 standard candles, and a 100-watt lamp, of 150 candles. The light is controlled either by a socket switch, as in the floor and table lamps, or by a wall switch for overhead lights. The three-way switch for lighting a lamp from two different places, as two different entrances to a room, or from upstairs and downstairs, deserves more frequent use, as it is a great step saver. You may find it interesting to follow out the working action of this switch, as disclosed in the diagram.

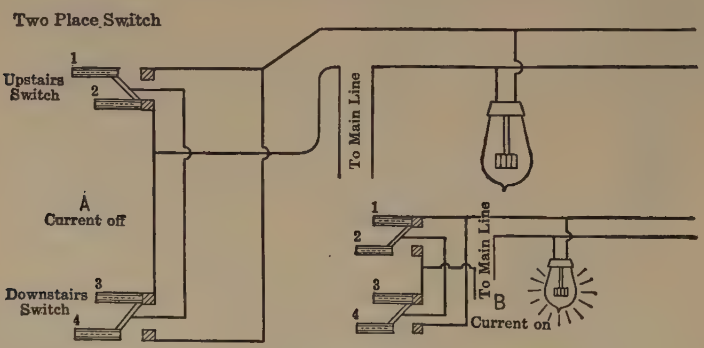


FIG. 207. — Wiring for a three-way switch.

The automatic circuit breaker and switch. A delicate bimetallic strip has been developed to operate upon any predetermined overload and open the electric circuit. Connected with this is a switch by which the current may be turned on and off by hand. This bimetallic strip

will turn the current off whenever the circuit is overloaded. With this device installed there is no need of a fuse in the circuit. Until the short circuit or overload is removed, the switch will automatically open every time you close it. This removes the danger and also the trouble of putting in new fuses. A person sometimes puts a 25-ampere fuse or a penny back of a blown fuse in a 15-ampere line. This is dangerous and may cause a fire. If a 15-ampere circuit breaker is used, you cannot get a dangerous current through the circuit. Its first cost is more than the ordinary switch, but considering the cost of blown fuses, and the trouble in finding the right circuit for the new fuse, the automatic circuit breaker is not costly in the long run.

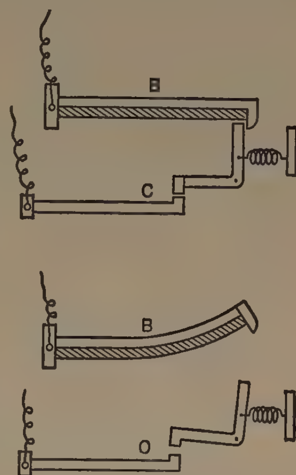


Fig. 208. — Circuit-breaker switch. *C*, closed; *O*, open.

Parallel and series connections. A pair of wires make up each of the branch circuits that run from the fuse box to a group of lamps. Each lamp is connected to both of the wires before we can get light. Perhaps ten different lamps are connected between the two wires. The current never flows through more than one lamp to pass from one wire to the other. Therefore, when all the lamps are turned on, there are ten paths through which the current is flowing. This method of connecting lamps is **multiple** or **parallel** connection. Our ordinary lamp can be operated safely on a

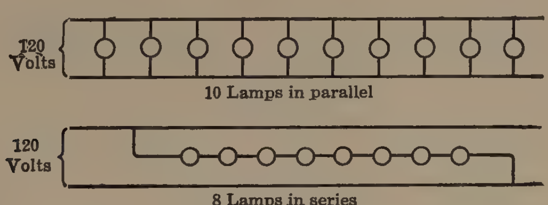


Fig. 209. — Parallel and series connection of lamps.

120-volt circuit. If the current were made to pass through one lamp and then a second lamp before it reached the return wire, there would not be enough energy to light the filaments. If we could take the filament out of the lamp, stretch it out, and cut it into eight equal lengths, and then put each short filament into a separate bulb, we would have eight lamps. We could now join these together and make the current

pass through them all before it reached the return wire, and they would all be lighted. These lamps would be connected in **series.** This is the plan for lighting many strings of Christmas tree lights. If one lamp burns out the other seven go out, because the circuit is open. If one lamp alone were connected across the two wires, it would burn out instantly, because the filament would be greatly overheated. The single lamp is only a 15-volt lamp, and it requires 8 times 15 to give sufficient resistance for 120 volts. Three 40-volt lamps can be joined in series in a 120-volt circuit.

Decreasing cost of electric light. The cost of any form of lighting must take into account the cost of the fuel or energy and the cost of materials used for a time and then replaced: in kerosene lighting, wicks and broken chimneys; in gas lighting, gas mantles; and in electric

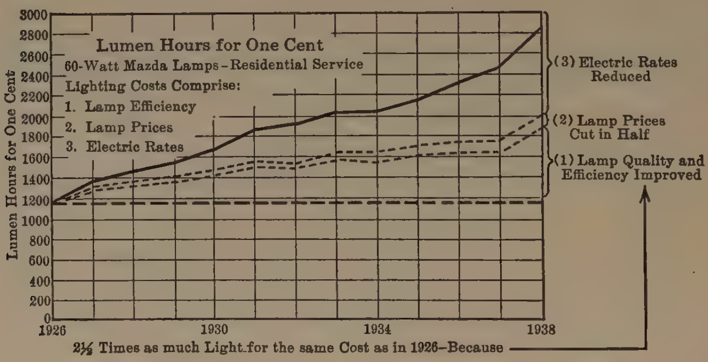


FIG. 210. — Decreasing cost of electric lighting.

lighting, new bulbs. Improvements which have come from scientific research have caused a remarkable reduction in the cost of electric lighting within a little over a decade. The chart shows how the amount of light received for 1 cent has increased over a period from 1926 to 1938. One lumen-hour is that amount of light that would fall upon an area 1 foot square, 1 foot from a standard candle, during 1 hour. In 1926 1 cent bought 1200 lumen-hours; in 1938, it bought 3000 lumen-hours of light when using a 60-watt lamp. The 60-watt lamp is a popular size: 50,000,000 of them are sold in the United States a year.

Use lamps at proper voltage. Filaments for lamps are made of such diameter and length that they will give the best service at a given voltage. When they are burned at a higher voltage a brighter light results but the life of the lamp is greatly shortened. When they are

burned at a lower voltage, a dimmer light results, which means lower efficiency. Burning lamps on undervoltage increases the cost of lighting. Lamp bulbs are always marked for voltage and watts. Your electric company will tell you the exact voltage of your circuit. A 2 per cent variation either above or below that marked on your bulbs is not a serious variation. The diagram shows graphically how you lose light in burning a 115-volt lamp on undervoltage circuits.

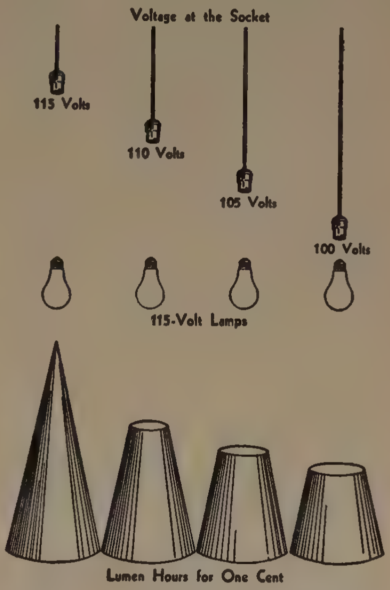


FIG. 211. — Graphic representation of loss of light when undervoltage burning occurs.

Bell troubles. If the bell does not ring, clean the wire connections and fasten them securely in the binding posts at both bell and battery. If it still fails to ring, failure is usually due to one of four things: a weak battery, improper adjustment of the contact screw, a broken wire, or a short circuit. When the battery is weak from long use, it must be replaced. The contact screw sometimes loosens and needs to be advanced slightly and tightened. Sometimes dust collects on the contacts, and cleaning the points is all that is needed. To make sure that the trouble is not in the push button, unscrew the cap and examine the wire connections there.

If a break in one of the wires occurs, you must locate the place. This is easily done as follows: join a bell in the circuit, close to one pole of the battery; keep the push button on closed circuit. Using a short wire with bare ends as a test wire, follow the pair of wires from the battery toward the bell, testing at intervals by removing a little of the insulation and joining the two wires with the test wire. The test bell will ring until you go beyond the broken wire. In Fig. 213 the test bell will ring with the wire at *A*.

The bell may fail to ring because of a short circuit. For example, if the two wires are fastened under the same staple, the insulation may wear through in time, and the staple may make a short circuit, thus preventing the current from reaching the bell. To test for a short circuit, place a bell in circuit as in testing for a broken wire, and close the button; the ringing of the test bell indicates a short circuit, and the wiring must be inspected until the short circuit is located.

The electric bell. The electromagnet finds many uses in the home. It is the chief instrument in getting mechanical motion out of electrical energy. One common household use of the electromagnet is found in the **electric bell.** The source of current is either a battery or a bell-

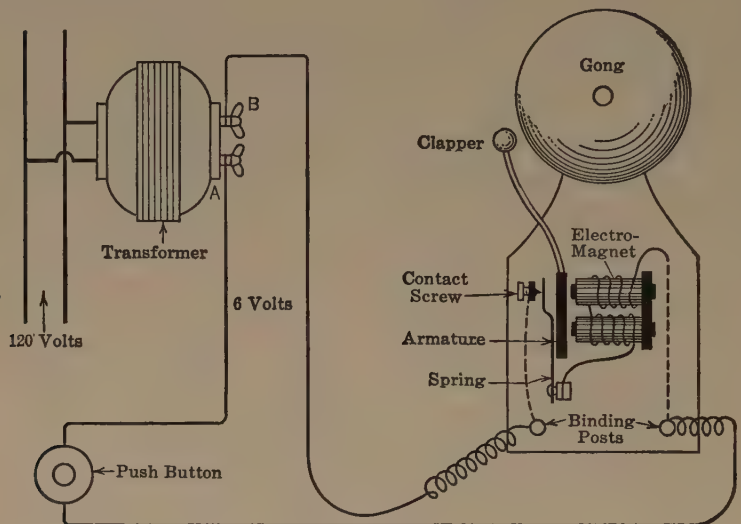


Fig. 212. — The electric bell connected to a transformer.

ringing transformer which steps down the city lighting voltage. The cost of using current from the lighting supply through the transformer is about the same as that for the renewal of batteries.

In the diagram of the electric bell, Fig. 212, follow the electrical connection through the system. Suppose that the circuit is closed by

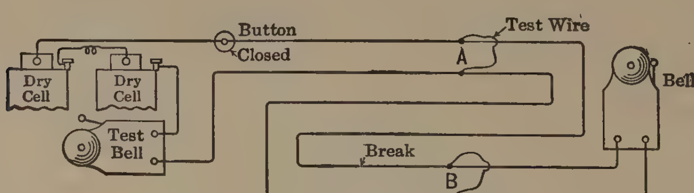


Fig. 213. — Testing the bell circuit to locate a broken wire.

pressing the push button. Starting at terminal *A* of the transformer, the current goes to the push button, to the binding post, to the coil of the electromagnet, to the armature, and contact screw. Then it goes to *B* and completes the circuit in the transformer. When the button is

pressed and the circuit thus closed, the current creates a magnetic field about the electromagnet. The soft-iron armature is then drawn toward the magnet and the clapper strikes the gong. After the armature has been drawn a short distance toward the magnet, it is separated from the contact screw. This breaks the circuit. The current ceases, the magnetism disappears, and the armature is brought back to its original position by the spring at its end. This closes the circuit once more, and the action just described is repeated. This action continues as long as the circuit is closed at the push button.

The telephone. Mechanical action caused by an electromagnet occurs in the telephone receiver. But to understand how we "talk" over the wire it is necessary to explain the transmitter first. This is not a device depending upon magnetic action, but one in which motion from voice waves causes variations in an electric current which affects a magnet in the receiver. The dial telephone has the transmitter and receiver joined in one unit; but each works on the same principle as the transmitter and receiver in the desk set which will now be described.

The telephone transmitter. The telephone in its present form uses many devices very different from those invented by Bell. The present-day transmitter is the invention of Blake, who applied the discovery

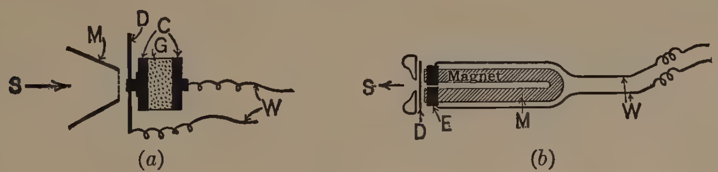


FIG. 214. — The telephone ear and the telephone mouth. At left, the transmitter. At right, the receiver. The telephone hears your voice and repeats your message at the other end of the line.

that pressure on granules of carbon changes their resistance to an electric current. By reference to Fig. 214A you will readily understand the arrangement of parts in the common carbon transmitter. Sound waves — vibrations in the air — come into the mouthpiece of the transmitter. These set the thin metal diaphragm vibrating. Every forward swing of the diaphragm compresses the carbon granules; every backward swing removes the pressure, thus allowing the carbon granules to separate a little. Suppose a current of electricity to be flowing through the carbon granules all the time. When they are compressed, their resistance is decreased and the current is increased. When the pressure is lessened, the resistance is increased and less current flows. Thus you

see that a sound wave, which makes the diaphragm move back and forth, causes the current in the circuit to vary in unison with the vibration of the sound wave, with the result that a pulsating current passes through the circuit. This pulsating current must be carried to the receiver at the other end of the line.

The telephone receiver. The receiver, as will be seen from Fig. 214B, has a permanent magnet with one end wound to form an electromagnet. Dolbear was the first to use a permanent magnet for the core of the electromagnet in the receiver. The action of the permanent magnet is so superior to that of the electromagnet with a soft-iron core that permanent magnets are found in all the millions of telephone receivers that are used daily. Just in front of the electromagnet is a soft-iron disc, or diaphragm. The production of sound takes place as follows: the fluctuating, or pulsating, electric current from the transmitter passes into the primary of an induction coil. This produces an alternating current in the secondary coil, which passes into the electromagnet coil of the receiver. The permanent magnet is alternately strengthened and weakened in unison with the sound waves which make the transmitter diaphragm vibrate. The receiver magnet, as a result of this varying strength, causes the diaphragm, which is close to it, to vibrate. This sets the air in front of it into vibration, and sound results.

The motor in the household. The use of electricity to perform mechanical work in the modern home is greater than one would at first suspect. The motor drives a current of air in the electric fan and the vacuum cleaner. It operates the clothes washer, the dish washer, and the clothes wringer. It mixes dough, beats eggs or cream, and squeezes the juice from fruit. Nowhere does the electric motor give more satisfaction than in the sewing machine. The motor is also used, though less frequently, for operating the ice-cream freezer, for grinding and polishing, and for other kitchen operations. In rural homes it has other valuable uses, such as pumping water, running the cream separator, shelling corn, and cutting ensilage.

How a motor works. In structure, a motor is like the generator; in fact, direct-current generators will run as motors. Mechanical energy is transformed by the generator into electrical energy, but the motor changes electrical energy into mechanical energy. Motion in the motor is brought about by magnetic action. In Fig. 215, current is brought through brush C to the segment of the commutator a and returns to the circuit through segment b and brush D. It passes around the soft-iron core of the armature AB in such a manner that the end A, which happens to be near the north pole of the field-magnet, is made a north pole.

Repulsion between the two north poles immediately occurs. Repulsion is also taking place between the two south poles at the other side of the armature. The south end *B* is attracted to the north field-magnet, and the north end *A* is attracted to the south field-magnet. Motion results from this attraction. Since the armature and the commutator rotate on a common axis, when half a revolution has been made, brush *C* is in contact with *b* and brush *D* with *a*, and so *B* is north and *A* is south. As a result of this change in polarity of the armature, the rotation, which was begun the previous half turn, is continued, and continuous rotation

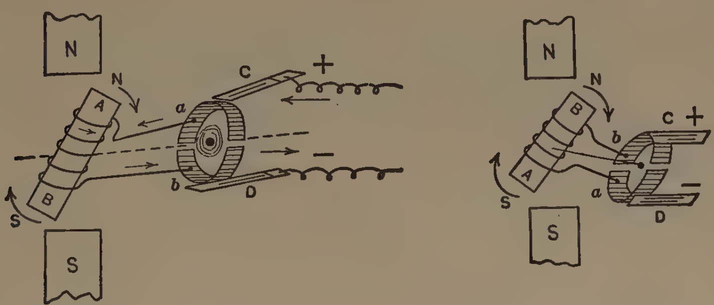


FIG. 215.—Principle of a simple electric motor.

is produced by the change in direction of the current in the armature every half turn. For alternating currents, a motor without brushes or commutator, called an **induction motor,** is used. An alternating current generator, if supplied with current from a second generator and brought up to the same speed as that of the second generator, will run as a motor. Motors operated on this plan are **synchronous motors.** They are not self starting. They are used in electric clocks. Small motors are now made which may be used with either the alternating current or the direct current. These motors have brushes and commutators.

Energy to run household motors. Many of our household motors require very little energy to operate them, and yet they save us much exhausting work. One thousand watt-hours or 1 kilowatt-hour will do about the same amount of mechanical work as a man will do in 8 hours. Because of the electric motor, electricity is a versatile servant, capable of pumping water, cleaning rugs, washing clothes and dishes, sawing wood, churning butter, and operating clocks, sewing machines, and fans. A snap of the switch sets the motors to work. Table XIX shows the usual energy consumption of motor driven household devices.

TABLE XIX

Energy Consumption by Electric Motor Devices

Device	Watts	Device	Watts
Telechron clock	2	Hand vacuum cleaner....	125
Electric fan	40	Refrigerator	170
Sewing machine	50	Floor vacuum cleaner ...	190
16-in. fan	110	Clothes washer	230
Winter air conditioner ...	115	Dish washer	415
Large food mixer	150	Kitchen waste disposal ...	500

Heat from electricity. In every conductor of electricity some electrical energy is changed to heat energy. In good conductors this change is small, but in conductors whose resistance is high it is large. There are metals and alloys which are far more resistant to the passage of electricity than copper or iron, and which do not oxidize when heated in the presence of air. Two of these alloys have been given the trade names Nichrome and Chromel. They are alike, however, in composition. The heating elements for electric ranges and furnaces are made of the very best alloy, consisting of 80 parts nickel and 20 parts chromium. In flatirons, toasters, and similar devices, a nickel-iron-chrome alloy of the following composition is used: 63 per cent nickel, 25 per cent iron, and 12 per cent chromium. If a Nichrome wire is bent into many loops, so that a very great length can be placed in a small area, a heating element will be produced. The wire for a heating element, in addition to having a high resistance, must have a very high melting point, and it should also resist oxidation. The best grade is called *Calorite.*

Electric radiator. Spirals of Nichrome wire wound around a fire-clay base are backed by a polished metal reflector. The wire is heated to a red heat, and the fire clay becomes so hot that it radiates much heat. The reflector helps to direct heat that comes to it in a direction where it will be useful. This device provides very effective radiant heat directly in front of the heater. There is some heating by convection. (See Fig. 110, p. 128.)

The modern heating element. The most durable and efficient heating element yet devised, particularly when exposed, is one in which a spirally wound coil of Calorite or Chromel wire is placed inside a metal sheath or tube and insulated from it by means of magnesium oxide. The spiral resistance wire is centered inside the sheath. The oxide, in powdered form, is sifted in and packed firmly about it. The tube is then put under pressure so that its diameter is reduced. This com-

presses the magnesium oxide into a rocklike mass. The heating element has the trade names Calrod and Corox. The sheath in reality is a tube made of an alloy of nickel, chromium, and iron, which is tough, hard, rigid, resistant to action of air, heat, water, and household chemicals and is a good conductor of heat. For some purposes the sheath is made of seamless copper tubing. The magnesium oxide, though

Fig. 216. — Construction of Calrod unit.

an insulator of electricity, is a good conductor of heat. The Calrod or Corox heating element may be used in almost all types of electric heating devices.

Electric iron. The heating element of the electric iron, well insulated from other metals, is placed in the base of the iron where its heat will be transferred quickly to the ironing surface. The element in some irons is a nickel-chrome ribbon wound around a mica base. In others the Calrod unit is used. Automatic irons contain a thermostat which maintains practically a constant temperature and prevents excessive overheating, which is a source of many fires. Some irons have an adjustable thermostat by which one can keep the iron at high, medium, or low ironing heat. Two circular metals having unequal expansion rates are welded together making a disc about 2 inches in diameter. This bimetal disc has three buttons for closing the circuit and is supported at its center. Expansion causes it to buckle and leave gaps in the circuit. Contraction causes buckling in the opposite direction, so that the circuit closes.

The electric toaster. In the common electric toaster, bare wire is arranged in loops in front of a rack which holds the slices of bread. The wire is of such size and length that the regular lighting current will heat it red hot. The hot wire is about 1700° F. and radiates so much heat that the bread is quickly browned.

The electric range. The electric range has increased in use within recent years because of lowered cost of electricity and improvements in the range itself. The most important improvement has been the production of a surface heating unit that is rapid heating, easily cleaned,

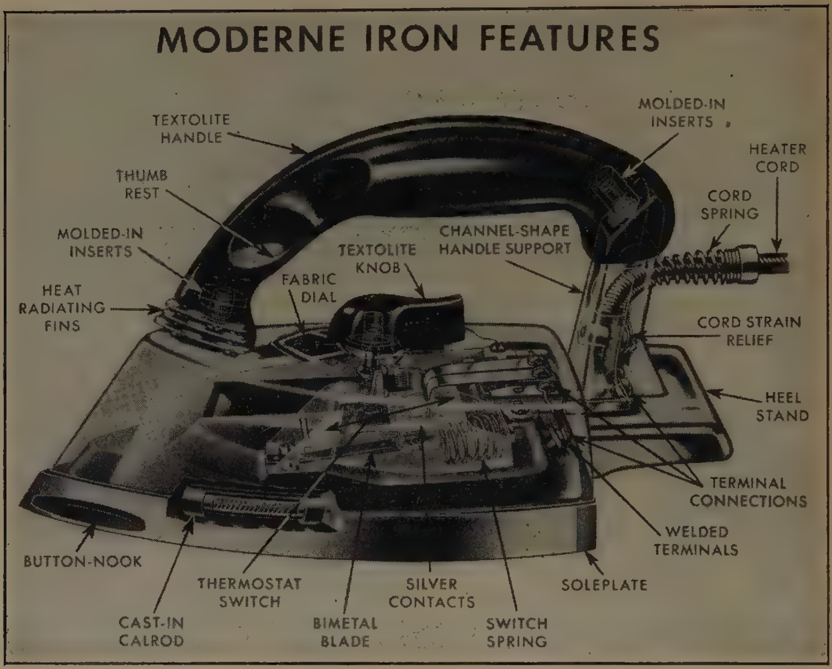


Fig. 217.—Phantom view of an automatic electric iron.

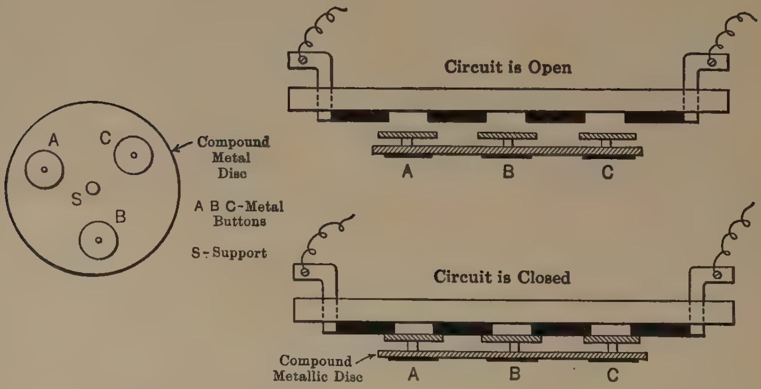


Fig. 218.—Thermostat of the automatic electric iron. At left: the compound disc which buckles and opens or closes the circuit. At right: the idealized section through the thermostat.

and not injured by food falling upon it or by "boiling over." Formerly the coiled wire for heating was exposed, and this had short life. The new unit, having a protective sheath, has a life five to seven times that of the old coil.

This new heating element — Calrod or Corox — has been described in a previous paragraph. These tubes serving as the heating element are bent into coils and flattened so that a saucepan will have greater surface contact and receive heat quickly by conduction. Much heat that is radiated downward is reflected back so that the cooking utensil also gets much heat by radiation. A quart of water in a "bright-bottom" aluminum vessel can be warmed from 50° to 207° F. in 8 to 9 minutes by a 1200-watt unit operated at 115 volts. Faster heating is obtained in a "black-bottom" aluminum vessel.

Fig. 219. — Electric range.

The so-called thrift cooker is an insulated well on the surface of the range. It is designed for low heat and is capable of cooking several foods at one time. It is for boiling or steaming but does not have baking temperature. The electric oven has a top Calrod or Corox unit for broiling and a similar bottom unit for baking and roasting. The oven is well insulated, preventing loss of heat to the room. Moisture is retained during baking. There is no circulation of hot air in or around the oven as in coal and gas ranges.

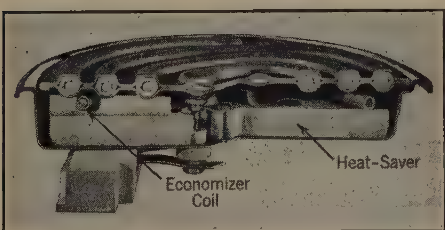


Fig. 220. — Section of heating unit.

Connections for different heats. The surface units of the electric range may have different cooking speeds; some have one, some three and others five speeds. High speed is desired in starting, but only moderate or low speed is required later. Fig. 221 shows how a

230-volt unit can produce five different speeds of heating according to the voltage and coils used. The connections are all controlled by the switch.

Electric range control. For the surface units when the switch is turned to "start" full current is sent through the coil to get heat quickly. When the food reaches cooking temperature the switch is turned to "cook" position. This takes only one-fourth the electric

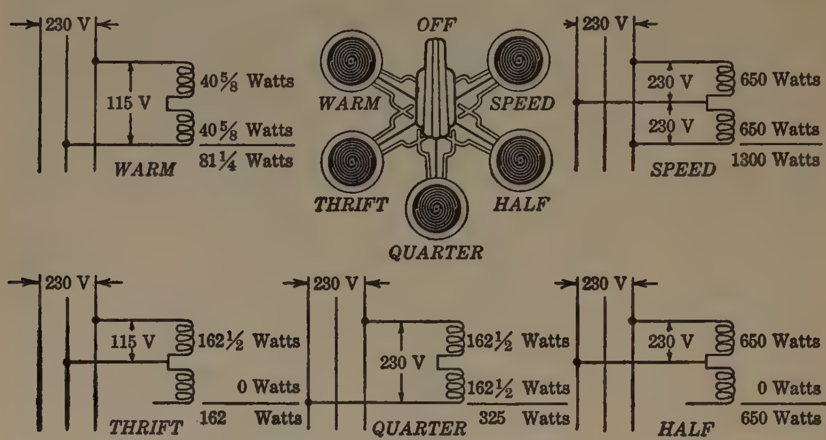


Fig. 221.—Line wire connections for five-speed switch on 230-volt circuit.

starting current. For the last 15 to 30 minutes of cooking the electricity can be turned off completely since the Calrod or Corox unit holds heat for a long time.

For baking in the oven, preheating is essential in order to have the oven at the right temperature when the food is put in. The proper oven temperature is taken care of by automatic control after the indicator has once been set at the desired temperature.

Cost of electric heat. The cost of electricity varies greatly throughout the country. In many places it varies with the quantity consumed. By means of a sliding scale the customer may pay much more for an amount about sufficient for lighting purposes, but in excess of that he pays much less. For example, a sliding scale might be this:

7 cents per kilowatt-hour for the first 20 kw-hr. each month
4 cents per kilowatt-hour for the next 30 kw-hr. each month
3 cents per kilowatt-hour for over 50 kw-hr. each month

By this means if electricity were used for heating it would average about half the rate paid for lighting. Table XX shows the average energy taken by lighting and heating devices.

TABLE XX

Energy Consumption of Light and Heat Devices

Device	Watts	Device	Watts
All-night light	5	Thrift cooker on range	600
Heating pad	40	Plate warmer on range	600
4-tube radio	50	Waffle iron	665
8-tube radio	100	Toaster	680
Soldering iron	125	Small hand iron	500
Sun lamp	160	Hand iron	1000
Oil furnace	200	Small surface unit on range	1200
Immersion heater	300	Large surface unit on range	2100
Larger sun lamp	490	Flat plate ironer	1320
Coffee maker	512	Oven	3000

SUMMARY

1. The house electric circuits includes many different parts besides the connecting wires, as: main switch, meter, distributing box and fuses, outlets and buttons or switches to devices.

2. Fuses are made of metals that melt at low temperatures. Their purpose in an electric circuit is to cut off the electricity when a short circuit produces excessive heat, which might cause fire. They, automatically, open an overheated circuit.

3. The most important use of electric heat is to make light. The tungsten filament can be heated nearly 200° C. hotter than the carbon filament in a vacuum bulb and nearly 600° C. hotter in a gas-filled bulb. Better light and more efficient change of electrical to light energy is secured by heating to the higher temperature.

4. For efficient service, electric lamps should be used at approximately the voltage marked on them.

5. When an electric device fails to work, the cause may be found in a loose connecting screw, a broken wire, insulation in the contact points, a blown fuse, or a burned-out heating element; or the power may be shut off.

6. The action of the electric bell is due to an electromagnet which draws an armature, with hammer attached, forward to strike a gong. In so doing it breaks the circuit, removing the magnetism and allowing the armature to return to its normal position, where it closes the circuit and then repeats its former movement.

7. Bell troubles may be due to: (1) a weak battery; (2) a broken wire; (3) a short circuit; or (4) improper adjustment of the contact points.

8. In the telephone transmitter, a box of carbon granules is placed in the circuit, so that sound vibrations alternately subjects them to greater and to less pressure. This increases and decreases the current in the induction coil and causes an alternating current to go to the receiver.

9. The telephone receiver receives the alternating current in a coil of wire around one end of a permanent magnet. Weaker and stronger magnetic fields are set up. Magnetic action causes a diaphragm to vibrate and thus send out sound waves which duplicate those striking the transmitter diaphragm.

10. Mechanical motion in an electric motor is the result of magnetic action. Properly timed electric currents through the armature commutator produce attraction and repulsion, resulting in continuous rotary motion.

11. Household motors using 1 kilowatt-hour of electrical energy will do about the same amount of mechanical work as a man working 8 hours.

12. Electric heat is popular because of its cleanliness and convenience. Only its high cost prevents it from being used more widely. The heating elements are composed of resistance wires, usually made of nickel-chromium alloys.

13. A bimetal thermostat controls the temperature of the automatic electric iron.

14. The modern electric range has heat elements protected by noncorrosive sheaths. A variety of cooking speeds is available.

15. Cost of electrical energy varies greatly. Many companies offer a sliding scale so that the cost for heating is less than that for lighting.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Make a plan of the house wiring at home. Indicate the fuses for each branch circuit, and locate all lamps and outlets belonging to each circuit.
2. High-tension electric transmission.
3. Report on a visit to the telephone exchange.
4. Test to see which costs more to run — an electric radiator or a gas radiator.
5. Cost of using electric range in my home.
6. Report on visit to local electric-light plant.

CHAPTER XVII

PROPERTIES OF LIGHT THAT MAKE IT USEFUL

What is light? Since man first began to think about natural phenomena there have been many ideas about light. Several theories have been set forth to explain what light is. The theory generally accepted at the present time is that light is a form of energy transmitted by ether waves which are capable of reacting upon nerves in our eyes to produce the sensation of sight. The *ether* which bears these waves is that intangible, weightless something which fills all space. It is between the molecules of matter and fills the space between the heavenly bodies. Vibrations in this ether constitute waves. Not all ether waves produce light. Heat energy and electrical energy are also transmitted as radiant energy by the ether. We find it easier to think of space as being filled with ether which may transmit radiant energy, yet we must remember that it is just a theory and that some of our greatest scientists believe radiations can travel across empty space without the assistance of any medium to carry them.

Radiant energy. Radiant energy is a term applied to any form of energy that is transmitted by means of ether waves. Experiments have shown that ether waves vary in length and in the number of vibrations per second. Different waves produce different effects. Very long ether waves carry *electricity,* used in the transmission of wireless messages. Shorter waves give us *radiant heat;* and still shorter waves, which affect the eye, are classified as *light.* Next come the waves which are too short to affect the eye, but which cause chemical action on photographic plates and in photosynthesis. These are in part *ultraviolet rays,* and include what are sometimes referred to as *actinic rays.* They are believed to have an important effect upon one's health. The X-rays are ether waves which are much shorter and include the gamma rays sent out during the breaking down of atoms in radioactive substances. The shortest ether waves, about which little is known but which are now engaging the attention of many scientists, are the *cosmic rays,* which may be emitted when atoms of matter are produced. The vibration rates of these various ether waves are shown in Fig. 222. The speed of ether waves is 186,000 miles per second. This is equivalent to 300,000,000 meters per second. The frequency, or number of vibrations per second, may be determined by dividing 186,000 by the wave length

expressed in miles or 300,000,000 by the wave length in meters. Some of the electrical waves are miles in length; the short X-ray waves are of ultramicroscopic dimensions.

Light waves. You are familiar with the circular waves produced whenever a pebble is dropped into water. The water rises and falls

Vibration Rate per Second	Wave Length in Centimeters	Type of Radiation	Application
10,000	3,000,000	Electrical waves (long waves)	Radio
401×10^6	74.8	Electrical waves (short waves)	
10^{12}	0.03	Heat	Stove
375×10^{12}	0.00008	Light	Electric Light
769×10^{12}	0.000039	Ultraviolet rays	Ultra violet Micro-scope; Storage of Starch; H_2O; Oxygen
220×10^{14}	0.0000000136	(Soft X-rays) X-rays (Hard X-rays)	X-ray
300×10^{17}	0.000000001	Gamma rays	Radium Tube
429×10^{17}	0.0000000007	Cosmic rays	Nebula
100×10^{22}	0.0000000000003		

Fig. 222. — Range of ether waves.

(transverse vibration) as the wave moves outward, making an ever larger and larger circle. Light waves are transverse vibrations in the ether; but, unlike the water waves, which spread out in a circle in one plane, the light waves are spherical in form. From any luminous point, waves pass off in spheres, which continue to increase in size until they meet some obstruction which deflects or absorbs their energy. Radii of these spheres represent the direction of motion of the waves, and any radius represents a part of the wave. That part of a spherical wave represented by a single radial line is called a **ray** of light. A group of rays make a **beam** of light.

In a given medium **light travels in a straight line.** Because of this we have shadows and we can direct beams of light in particular directions for useful purposes. Light is bent or **reflected** when it meets the

surface of matter. It is because of this that objects are visible to us, that we can use mirrors and see pictures on the theater screen. When light passes through transparent bodies of different densities it may be bent by a process called **refraction.** Refraction is utilized in lenses to correct eye defects, to make an image in the camera, and in a great many optical devices used in everyday life and by the scientist. Light, then, has three very important physical properties: (1) it travels in straight lines; (2) it can be reflected; (3) it can be refracted.

What becomes of light? When a beam of light meets any kind of matter three things may happen to it. It may be *reflected, transmitted,* or *absorbed.* When light comes to clear glass most of it is transmitted, as is shown in Fig. 223. That which is absorbed is changed to heat. All substances reflect some light and absorb some. Highly polished surfaces and mirrors reflect much more than dull, black surfaces do. Non-luminous bodies are seen only by the light which they reflect. Thin paper and oiled paper, which transmit enough light to permit bodies to be seen indistinctly through them, are called *translucent* or *semi-transparent* bodies. Glass, clear mica, and pure water transmit a large amount of light and permit objects to be seen distinctly through them. They are *transparent.* Iron, wood, earth, and brick do not allow light to pass through them. Such bodies are *opaque.* Conditions may change the classification of substances in these three groups. For instance, thin paper may be translucent, but thick paper, opaque. Ordinary gold is opaque, and yet very thin sheets of gold are transparent. Ordinary glass is transparent, but ground glass is translucent, or even opaque. When light energy is absorbed by opaque bodies, it causes greater molecular vibration and becomes heat energy. When absorbed by the green chlorophyll of growing plants, however, it is changed to chemical energy and is the means of producing starch and sugar in plants.

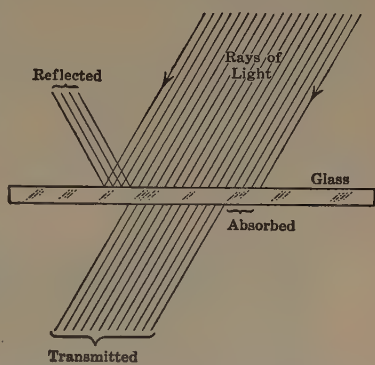


FIG. 223.— Glass does not transmit all the light that falls on it.

Shadows. You cannot see around a corner. This is because light travels in straight lines. One consequence of this property of light is the shadow. When light falls upon an opaque body, the space behind it is dark; this darkened space is the *shadow.* A shadow is not the surface in one plane which we often see upon the ground; it is the entire

space (three dimensions) from which the light is cut off. The **umbra** is a shadow produced when all the light is cut off from a given space; the **penumbra** is a partial shadow produced when only a part of the light is obstructed. Eclipses of the sun and moon occur when the earth or the moon traverses the shadow which is cast by one of the bodies as it passes between the sun and the other body. In Fig. 224 an eclipse of the sun is shown. Where the umbra of the moon touches the earth, the sun is in total eclipse. Under the penumbra a partial eclipse is observed.

Fig. 224. — Total eclipse of sun.

Laws of reflection. If a plane mirror is held in a beam of light in a dark room, the beam will be reflected. A line perpendicular to the mirror at the point where a ray of light strikes it is called a **normal.** A single ray of light coming to the mirror is an **incident ray**; one coming from the mirror is a **reflected ray.** By turning the mirror back and forth, various angles will be made between the incident ray and the normal. These angles are **angles of incidence.** In each case it will be observed that the angle between the reflected ray and the normal is equal to the angle of incidence. The angle between the reflected ray and the normal is known as the **angle of reflection.** The relation of these angles is stated in the law of reflection: *The angle of reflection is always equal to the angle of incidence.*

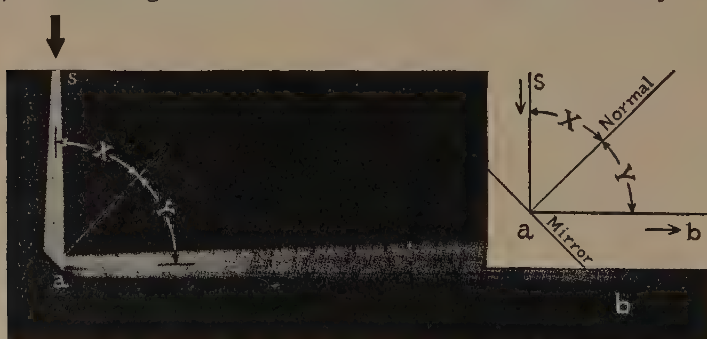


Fig. 225. — Reflection from a polished mirror. The angle of incidence (x) equals the angle of reflection (y).

Diffuse reflection. If a mirror reflects a strong beam of light to the eye, it produces a blinding glare, but if a piece of soft, white cloth replaces the mirror, the glare is removed. No well-defined beam of

light is reflected from the cloth, but instead, a much larger space is lighted to a lower intensity. This scattering of light is called **diffusion.** The explanation of diffusion of reflected light is readily understood from

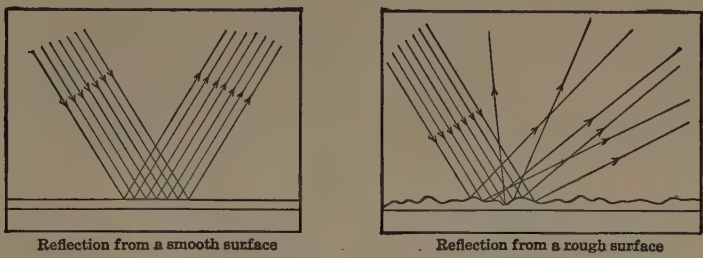


FIG. 226. — A rough surface scatters the rays of light, causing diffusion.

a study of two diagrams showing light reflected by a smooth and a rough surface. *Diffuse reflection* is produced by plaster, blotting paper, "flat" paints, and rough surfaces in general. Diffusion of transmitted light is also caused by a rough surface, such as ground glass, and by substances which interfere with the direct transmission of light, as opal or milk glass. When glass that is frosted on one side is placed in a beam of light so that the light comes to the smooth surface, a strong

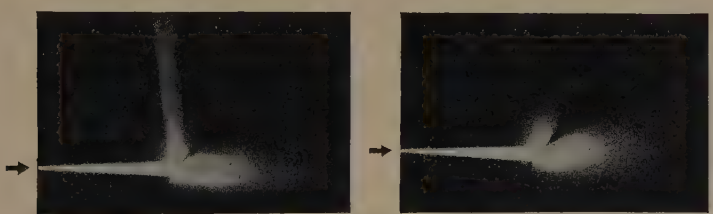


FIG. 227. — Reflection and transmission of light by frosted glass.

beam of regularly reflected light results; but when the frosted surface is toward the source of light, the reflected light is diffused. Transmitted light is diffused in both cases.

Images in a plane mirror. Standing in front of a mirror, you appear to see yourself behind it. As you approach the mirror, your image approaches. If you step back, your image moves back. The explanation of the image and its position behind the mirror is simple. Rays of light from each point on the object are reflected by the mirror to the eye. Objects appear to be in the direction in which light comes to the eye. The object one sees by means of the mirror is not in the

direction in which the light comes; hence, what is seen is termed the **image.** The distance between the image and the eye is judged by the angle made by the rays which enter the eye. They appear to meet at a distance back of the mirror equal to the distance of the object in front of the mirror. The image is unreal, or *virtual;* that is, if the eye is not

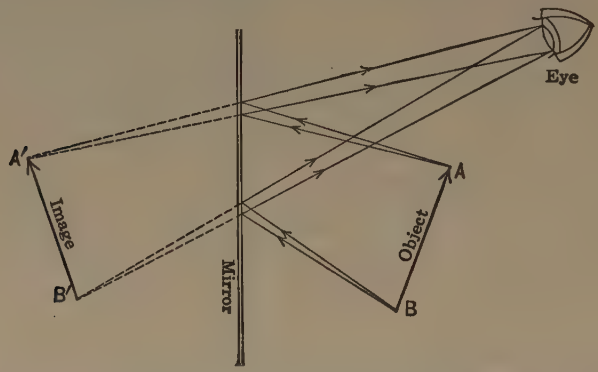


FIG. 228.—A plane mirror changes the direction of the rays of light so that an object AB appears to be at $A'B'$.

looking into the mirror there is no image back of it. Experiments show that the image and object are equidistant from the mirror and are of the same size, but that the image is reversed.

Concave mirrors. Rays of light parallel to the perpendicular axis (the line connecting the center of the mirror with the center of curvature), when reflected by a concave mirror, meet at a point on the principal axis, called the **principal focus.** If the source of light is nearer, so that the rays are diverging, rays from any point on the object will focus farther from the mirror. An image is produced where the rays are brought to a focus. The chief purpose of such mirrors is to reflect light in useful directions. If a source of light is placed at the principal focus, the light which strikes the mirror will be sent back in a beam of parallel rays. This gives an intense beam of light that reaches for a long distance. The **parabolic mirror** is much used in small searchlights and automobile headlights. By placing the light a little nearer the reflector than the principal focus, the beam of reflected light is spread slightly. Searchlights throw a powerful beam of light, visible a hundred miles away.

Refraction. When light goes from one medium to a medium of different density, its speed is changed. All transparent bodies decrease the speed of light slightly; the denser the body the greater its effect. When a beam of light goes from air to water, it must enter the water either

perpendicularly to the surface or obliquely. If it enters perpendicularly, the entire wave front enters the denser medium at the same instant, and all of it is slowed up. In this case there is no bending, but the beam continues on through the water in the same straight line. If the beam is oblique to the surface, some rays will enter the water while others are still in the air. The result of this will be apparent by a study of Fig. 230. *ABCD* are different rays in a beam of light passing from air to glass. The line *ad* is a wave front. Consult Fig. 230, part 2, and apply the following explanation: When *B* travels from b^1 to b^2, *a* has traveled from a^1 to a^2. When *D* has traveled from d^1 to d^4, *A* has traveled from a^1 to a^4. Since

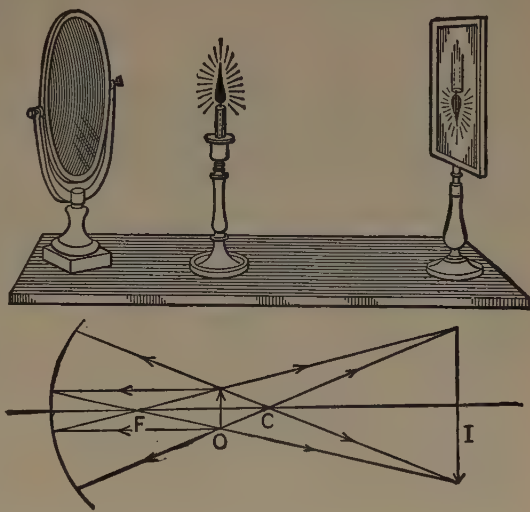


Fig. 229. — How a concave mirror produces an image.

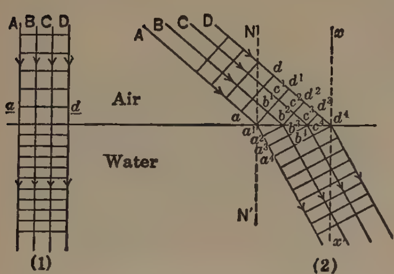


Fig. 230. — Refraction of a beam of light in passing obliquely from one medium into another of different density.

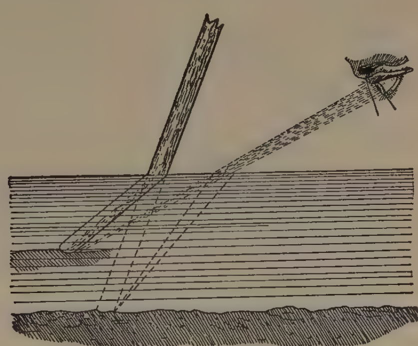


Fig. 231. — How refraction changes the apparent position of objects seen in the water.

a^1a^4 is shorter than d^1d^4, the wave front, a^4d^4, in glass cannot be parallel to the wave front in air. Not only is the direction of the beam changed in the glass, but the beam is wider than in the air. The bend-

ing of light rays on entering a medium of different density is called **refraction.** It is because of refraction that objects standing partly in water often appear bent or broken, and the depth of a stream appears less than it really is.

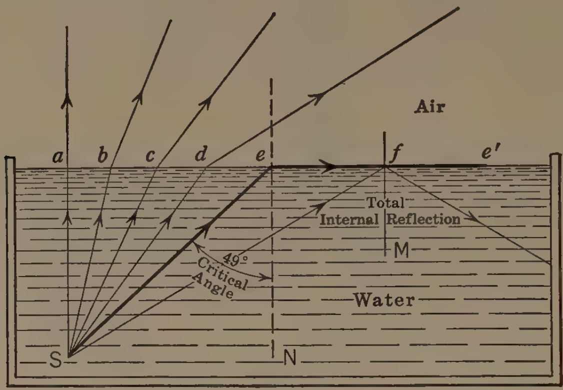


Fig. 232. — Refraction and total internal reflection.

Law of refraction. By reference to the diagram explained in the previous paragraph, it will be seen that in passing from air to water light is bent *toward the normals NN′ and xx′.* If, however, it passes to the air, it is bent *away from the normal.* The **law of refraction** is stated thus:

When a ray of light passes from a rarer to a denser medium, it is bent toward the normal; when it passes from a denser to a rarer medium, it is bent away from the normal.

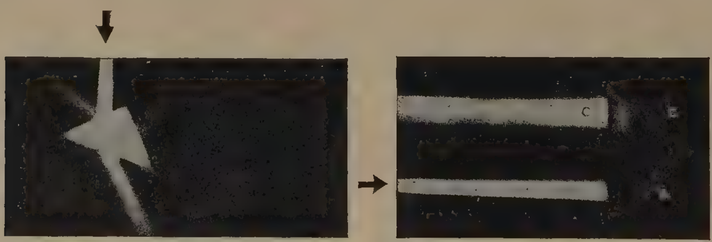


Fig. 233. — Refraction (at left) and total reflection (at right) by a right-angle prism.

Refraction and reflection by prisms. An oblique ray of light coming from a glass prism by refraction is bent toward the surface of the glass. The larger the angle of incidence the nearer the surface the refracted ray comes until finally the refracted ray coincides with the surface of the prism. A ray of light at a still larger angle will no longer be refracted but will be totally reflected within the glass.

This can readily be demonstrated by sending rays of light from beneath the surface through water. In Fig. 232 the ray *Se* is a ray of light from *S*, which is refracted along the surface *ee'*. The angle *SeN* is the critical angle. Any angle between the incident ray and the normal larger than this, as *SfM*, will result in total reflection of the ray back into the water. The critical angle for water is 49°. For crown glass it is about 43°.

In a right-angle prism, Fig. 233, a beam of light which comes in one side of the long surface, at right angles to the surface, travels without refraction through the glass to one of the short surfaces (*a*). It meets this at 45° and is reflected to the other short surface (*b*), where it is again reflected and sent back out of the long surface (*c*) in a line parallel to the entering ray. This principle is used in binocular glasses and in prismatic ribbed glass reflectors.

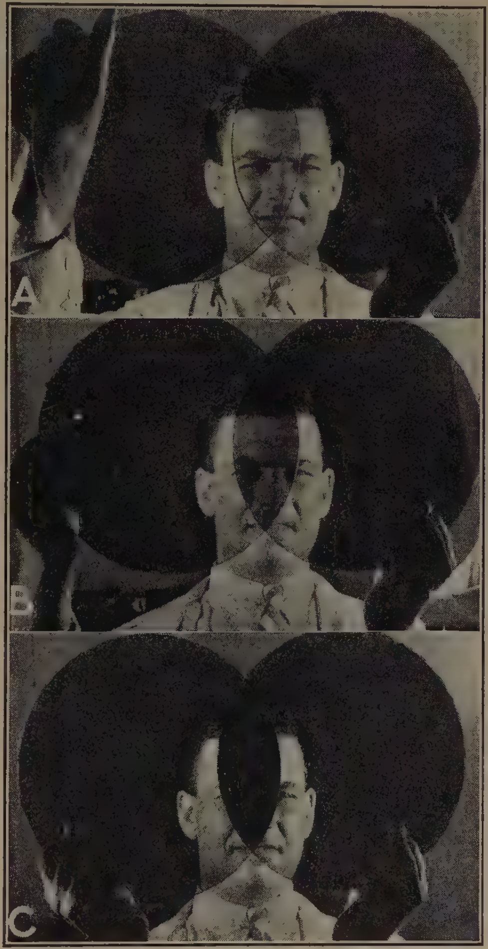


Fig. 234. — Polaroid discs showing in the overlapping section the vibration planes: *A*, parallel; *B*, at 45° angle; and *C*, at 90° angle.

Polarized light. Light behaves as if it traveled in waves which are vibrations transverse to or across the path of the wave. These transverse waves are in all planes. A large number of them may be considered as up and down vibrations, whereas others vibrate at right angles to these or from side to side. There are still others oblique to these. Most transparent bodies allow all these waves to pass through, but some allow only those vibrating in one plane — say up and down — to pass through. These selected rays are called *polarized* light. A

transparent tourmaline crystal allows rays whose vibrations are parallel to its long axis to pass through and excludes all others. If two tourmaline crystals are held together at right angles they will shut off all light

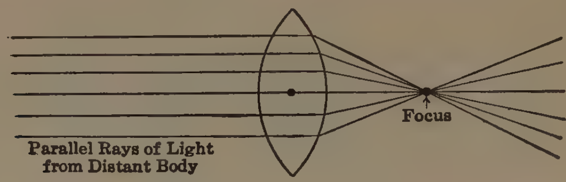


Fig. 235.—Focus of parallel rays by a convex lens.

where they cross. Polarization has not been possible except in a very limited way until recently, as it was limited to small areas of natural crystals. Since the invention of Polaroid film by Edwin H. Land of Boston, polarization is receiving much greater attention. Polaroid film can be made in sheets of almost any desired size and is finding many practical uses.

Lenses. Common lenses are either **convex** or **concave.** Their surfaces are portions of spheres. The center of the sphere of which each surface is a part is the **center of curvature.** The center of a lens having two curved surfaces is called the **optical center.** The center of the curved surface of other lenses is the optical center. A line passing through the center of curvature and the optical center is the **principal axis.** When rays of light parallel to the principal axis enter a double-convex lens, they are refracted and cross each other on the other side of the lens in a point which is called the **principal focus.** The principal

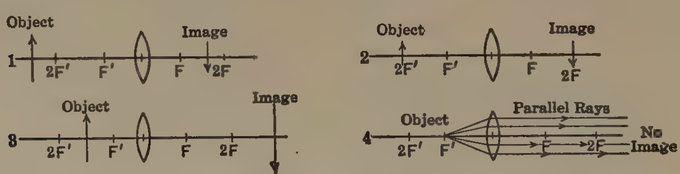


Fig. 236.—Relation of image to object under varying distance of object from lens.

focus nearly coincides with the center of curvature. The distance from the principal focus to the optical center is the **focal length** of the lens. This may be determined by holding the lens in the sunlight and moving a paper screen behind the lens until the brightest image is produced. The heat concentrated on one spot in this way will sometimes set fire to paper; hence the lens is often called a "burning glass."

Images in lenses. When a convex lens is held between a screen and a bright light in a darkened room, and moved toward the screen or toward the light, some point will be found where a clear image of the light will be produced on the screen. This is a *real* image, because it is there whether you are looking at it or not. The rays of light, after passing through the lens, can be focused on the screen. The image of

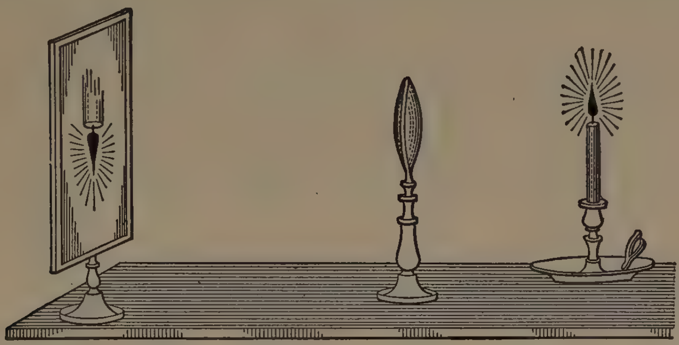


Fig. 237. — A convex lens produces a real image but inverted; it may be larger or smaller than the object.

an object is produced where light from the object is brought to a focus as shown in Fig. 236. The images produced with a concave lens cannot be thrown upon a screen. They are *unreal* or *virtual* images.

Construction to locate images. When the image of an object is produced by a lens, the image of any point on the object may be located

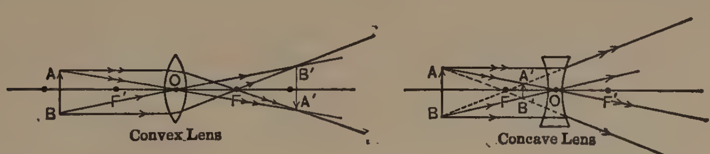


Fig. 238. — Construction lines needed in locating images of objects through lenses.

by tracing two of the rays of light. Draw a line from the point to the lens, parallel to the principal axis. This will pass through the principal focus on the opposite side of the lens in convex lenses, and in concave lenses it will bend away from the principal axis at such an angle that, if it were prolonged, it would pass through the principal focus on the same side of the lens as the object. Draw a second line from the point through the optical center. This ray is not refracted but continues on unbent. The point where these two lines cross each other is the focus of

all rays of light passing from the point on the object to the lens, and hence it marks the position of the image of the point. The images of other points on the object are determined in a similar way, and thus the image of the object is located.

SUMMARY

1. Light is due to waves in the ether, which give us the sensation of sight.

2. Other ether waves, which differ from light waves only in their frequency of vibration, are those of electricity, heat, ultraviolet rays, the X-ray and cosmic rays.

3. A light wave travels outward in a hollow sphere. A radius of the sphere represents a ray of light. Light may be reflected, absorbed, or transmitted. Bodies are opaque, transparent, or translucent, depending upon their ability, respectively, to obstruct the passage of light, to transmit it freely, or to transmit and at the same time diffuse it.

4. Light travels in a straight line. A shadow is the space from which light is obstructed by an opaque body. Eclipses occur because of the passage of one heavenly body into the shadow of another.

5. A plane mirror reflects light in such a way as to make equal angles on either side of a perpendicular at the point of incidence.

6. The law of reflection: The angle of reflection equals the angle of incidence.

7. Uneven surfaces and translucent bodies scatter or diffuse the light.

8. An image is as far behind a plane mirror as the object is in front of it.

9. A concave mirror focuses the light upon one point, except when the source is at the principal focus or between that point and the mirror. Concave mirrors of the parabolic type are much used in automobile headlights because they give a beam of nearly parallel rays.

10. All light passing into a denser or a less dense medium, at any angle except a right angle, is bent from its original direction. This bending is called refraction. When passing to a denser medium, light bends toward the normal; when passing to a less dense medium, it bends away from the normal.

11. The incident angle within a substance at which a refracted ray coincides with the surface is the critical angle of that substance. When the angle of incidence is greater than the critical angle, total internal reflection occurs.

12. Polarized light consists of rays which vibrate in the same plane. Some natural crystals and Polaroid — a manufactured product — are

transparent only to those rays vibrating in a given plane, all others being excluded.

13. Because of refraction, light, in passing through a lens, is focused so as to produce images in various places, depending upon the position of the object giving out the light. Light from distant bodies comes in practically parallel rays, which are brought to a point at the principal focus by a convex lens. The distance from the principal focus to the center of the lens is the focal length of the lens.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Images in mirrors and in lenses.
2. Apparent displacement of bodies through refraction.
3. Study the reflection, refraction, and diffusion of light with the optical disc.
4. Use of polarized light.
5. Principle of periscope.
6. Reflection by right-angle prisms.

CHAPTER XVIII

SUNLIGHT

Where do you live? Is it in the open plain with full sky above or is your house sheltered by large trees with dense foliage? Are you on the southern or northern slope of a hill? Perhaps in a city facing a park, or might it be in a tall apartment house on a narrow street with tall apartment buildings opposite? Does your house face north, east, south, or west? Sunlight is such an important factor in its effect upon our lives that it is important to consider conditions which are favorable and those which are unfavorable to our health, comfort, and pleasure.

Natural light in the home. Not all sides of the house receive equal amounts of light. North windows receive direct sunlight only in the early morning and late afternoon in summer, and not at all in winter. Practically all light coming to north windows is from the sky, which gives a subdued sunlight reflected and diffused by the particles of dust and moisture in the air, and by the air itself.

The usual practice of allowing window space to equal one-fourth of the floor space for most rooms, and one-sixth of the floor space for sleeping rooms, may or may not be satisfactory. Frequently, obstructions to sunlight and sky light may seriously interfere with efficient lighting. In planning the window space, one should consider the obstruction of light by high ground or cliffs, tall buildings close by, trees now present or likely to grow, and piazza or porch roof. On the east and west sides of the house, which are without sunlight for a portion of each day, as well as on the north, the amount of sky visible from the windows is important, for, when these windows do not receive direct sunlight, the rooms must be lighted by sky light. If there is too much light, it must be regulated by controlling devices, such as awnings, blinds, shades, curtains, or draperies.

Sunlight is an important factor in health. Its absence favors the survival of disease germs and reduces man's resistance to disease. Lack of sunlight is one cause of rickets in children. Much of the ricket-preventing quality of light is lost when it is filtered through window glass; hence the desirability of exposure to outdoor sunlight. Light is a germicide and promotes good health. Its use makes photography possible. Our food is derived directly or indirectly from plants, which cannot grow in darkness.

Facing the sunlight. The orientation of the house is considered of great importance by many architects. Study of the diagram (Fig. 239) will show that except for a short time in summer no direct sunlight can enter north windows. Little-used rooms and hallways when possible should be placed on the north. Rooms used much of the time as living room and kitchen are best with a south exposure. The sun is at such high altitude in summer that it does not shine far into south windows. But at the low altitude of winter it does reach deeper into the room.

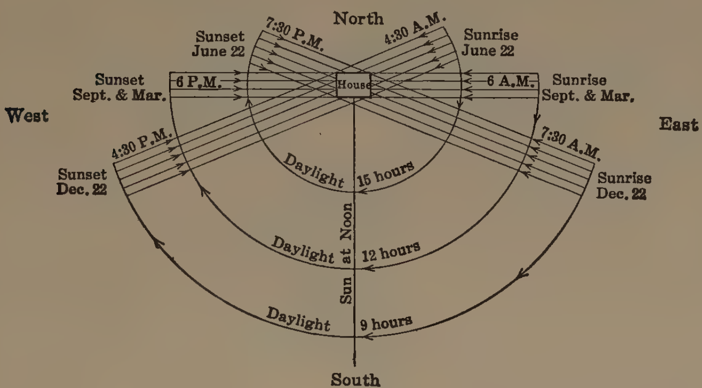


Fig. 239. — Direction and duration of sunlight for the different seasons. How many hours will a December sun shine into an east window?

Sources of natural light. There are many reasons why sunlight is so important to us: it makes objects visible; it produces heat; it brings good cheer. Except for such trivial amounts of light as come from stars, from the northern lights, from phosphorescent light produced by animals, and the like, our natural light comes from the sun. The sun is, as well, the great source of the earth's energy, which we find stored in coal, in running water, and in moving air, or the wind. It is estimated that 45 per cent of the sun's total energy is given out as visible light. Our own energy for work may be traced back to the sun. The sun is some 93,000,000 miles away, and yet its energy, in the form of heat and light, traverses this distance in the short space of 8 minutes and comes to us at a speed of 186,000 miles per second.

The warm southern slope. Since the sun's rays are brought to the earth in parallel lines, the angle at which they meet the earth determines the heating effect. It is common knowledge that a southern slope is warmer than a northern slope, and therefore more desirable for an early garden. In Fig. 240, *AB* and *BC* are equal beams of radiation from the sun. Study the diagram until you can explain it. The air

absorbs a considerable part of the radiant energy which passes through it. We know that clouds shut off the light and heat of the sun. Ex-

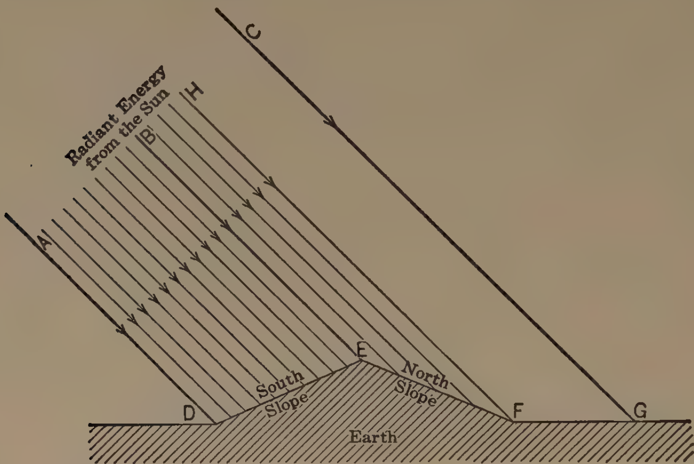


FIG. 240. — A southern slope intercepts more of the sun's rays than a northern slope of the same area.

periments made by Langley show that the greater the depth of air through which radiation comes the less the radiant energy received. His experiments were conducted at the base and summit of a mountain about 15,000 feet high, and the results are indicated graphically in Fig. 241. Both the total radiation and the proportion of ultraviolet light are greater at the summit than at the base of the mountain.

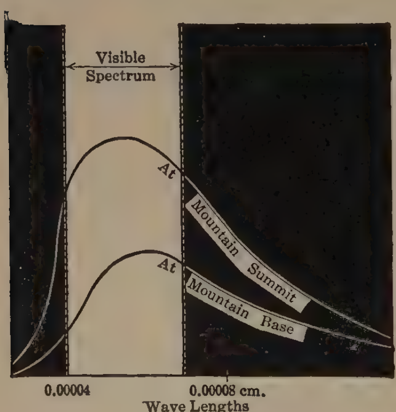


FIG. 241. — The intensity of the sun's rays is decreased by passing through a greater depth of air.

Radiant energy from the sun. The three most important radiation effects of the sun are the *chemical*, *light* and *heat* effects. Figure 243 shows the distribution of these three forms of energy in average sunlight. We are more or less familiar with the heat and light effects, and the chemical effects, though less understood, are just as important. You have observed that clothing, carpets, and wallpaper fade. Colored materials do not fade if ultra-

violet light is excluded. Fading is due to chemical change brought about by the so-called chemical rays. Artificial violet rays are used

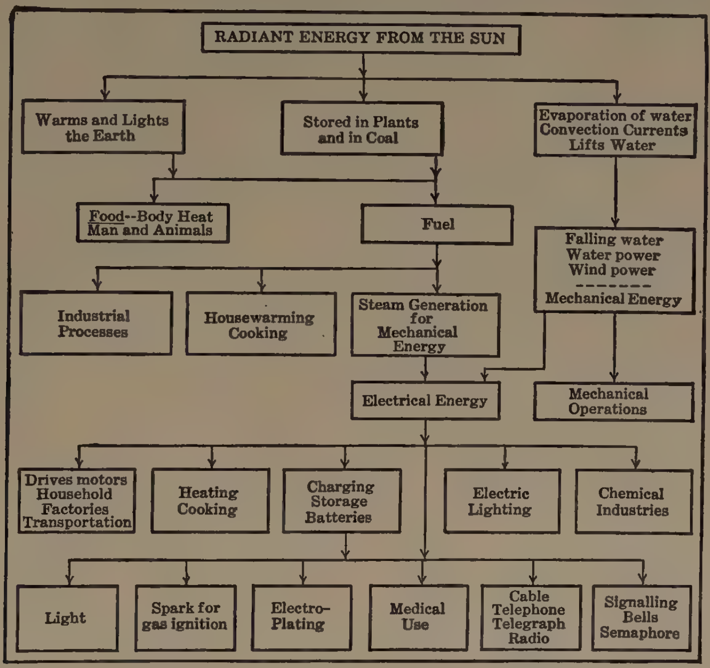


FIG. 242.—Every form of energy we use can be traced back to the sun.

in chemical industries, as in the tanning of leather, in sterilizing water, and for certain health treatments.

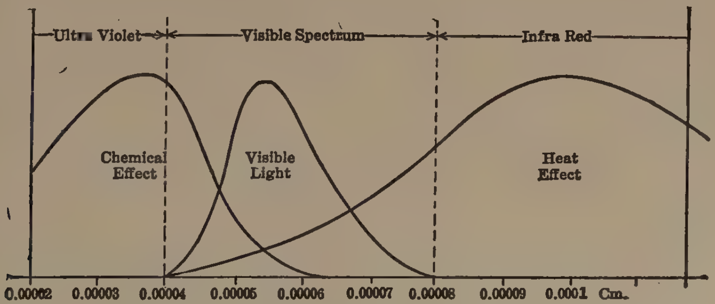


FIG. 243.—Distribution of ultraviolet, light, and heat rays from the sun.

Absorption of light energy by matter results in heat energy. The *cold frame* used by gardeners in early spring is, in reality, a kind of trap

to "catch" heat. Radiant energy easily passes through the transparent glass and warms the soil, which in turn warms the air. The warm air cannot escape by convection or by wind action, as it does over the uncovered earth. The radiant heat from the earth passes through the

FIG. 244. — When two boxes of earth *A* and *B* are exposed to the sun's rays, *A* being open and *B* closed with glass, a thermometer will register a higher temperature in *B*. This is the principle underlying the use of the cold frame.

glass less readily than the radiant light energy from the sun. This is an important factor in the value of the cold frame, because about half the energy radiated by the sun is the luminous, or light, energy. The temperature of the soil, both in and out of a cold frame, depends largely upon the angle at which the sun's rays strike the earth.

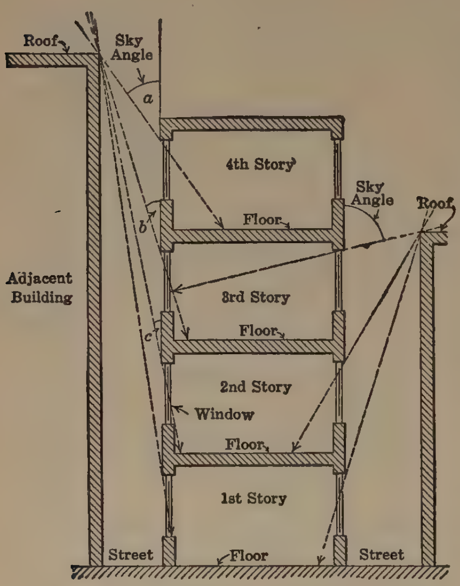


FIG. 245. — The amount of light in an apartment house frequently depends upon the nearness of adjacent buildings.

Sky light. Sunlight is diffused by the air through which it passes, so that we receive light from all parts of the sky. Were this not true, our north windows, except for three hours a day in midsummer, would receive no more light in the daytime than they do at night. Because of this valuable source of light, it is important to consider the sky angle (arc of the sky) which is visible through the window from remote parts of the room. The brilliancy of the sun is some 200,000 times that of the sky, and yet this rather feeble sky light is of inestimable importance to us. The visible sky angle should be at least 5° at any part of the room where work is being done which requires as much light as reading.

Hills, trees, shrubs, and buildings frequently obstruct light and decrease the visible arc of the sky. Such obstructions are particularly bad if on the north, where practically all light must come from the sky.

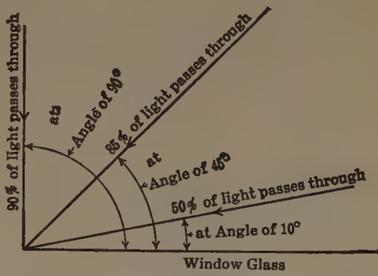


FIG. 246. — The greater the angle between the incident ray and the glass, the greater the amount of light transmitted.

Sky light in apartments. Country and suburban houses may easily secure good natural light, but the city apartment is usually less favorably situated. As a rule, windows are on the front and back of the house. Little, if any, direct sunlight is available, and even the arc of the sky, which can throw its diffused sunlight into the windows, is frequently inadequate to make good lighting conditions. Particularly is this true for the lower floors. Consider a four-floor apartment which is facing a five-floor apartment across a narrow street, or which backs up against it across a narrow alley in the rear. By consulting Fig. 245, it will be seen that the sky angle for the window on the fourth floor is widest. The sky angle decreases for windows on lower floors (see angles *b* and *c*), and no direct sky light at all enters rooms on the first floor. Moreover, as the angle of incidence increases, the amount of light transmitted by ordinary window glass is diminished. The amount of light transmitted at various angles is shown in Fig. 246.

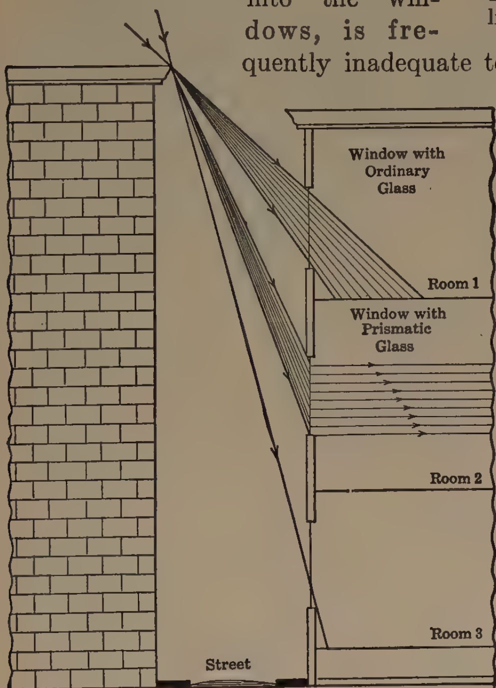


FIG. 247. — Prismatic glass makes it possible to bring natural light to the rear of some rooms which would be very dark with ordinary window glass. See room 2 above.

The light in these lower rooms may be increased many times by having, in the upper sash, *factory ribbed glass* with about twenty-one ribs

to the inch, or by means of *prism glass*. In rooms on light shafts, prism glass will often increase the amount of light fifteen or more times. The prismatic glass is more efficient than the ribbed, but it is also more expensive. It is important to select prismatic glass with the proper angle of prism to meet the needs of a given room. After refraction, the light is reflected by the lower surface of the prism. The reflected ray will be refracted again as it enters the room, unless it is a horizontal ray. Study the diagram shown in Fig. 248. The direction of the light from the sky to different windows varies, and without proper prism angles the light received by the glass might be reflected to the ceiling, rather than to the back of the room.

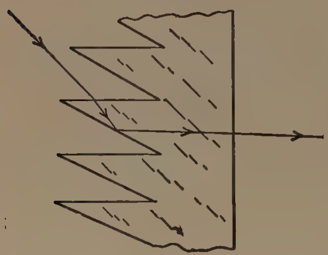


Fig. 248. — How prismatic glass changes the direction of a ray of light.

The reflection of light from opposite buildings is an important factor in lighting lower floors. Light-colored buildings are much better reflectors and so give better lighting. Lower floors frequently receive considerable reflected daylight, when no direct sky light is received.

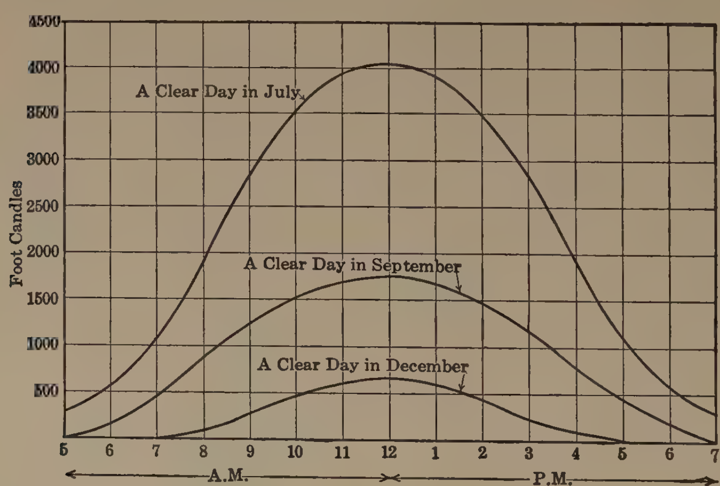


Fig. 249. — A comparison of daylight intensities at different seasons.

The daylight efficiency of the house. In order to measure the daylight efficiency of your house for any particular place where you are using daylight, it is only necessary to measure the illumination at that point, and to compare it with the illumination in a free space out of

doors. The ratio of illumination at one point within the house to the illumination out of doors is the **daylight factor**, or **daylight efficiency**, of a building. This runs from a fraction of one to several per cent. If you know what intensity of light is required for a particular piece of work, the daylight factor, and the intensity of outdoor light for the particular time in question, you can then find out how much, if any, artificial light is required. This will also indicate how efficient the house is

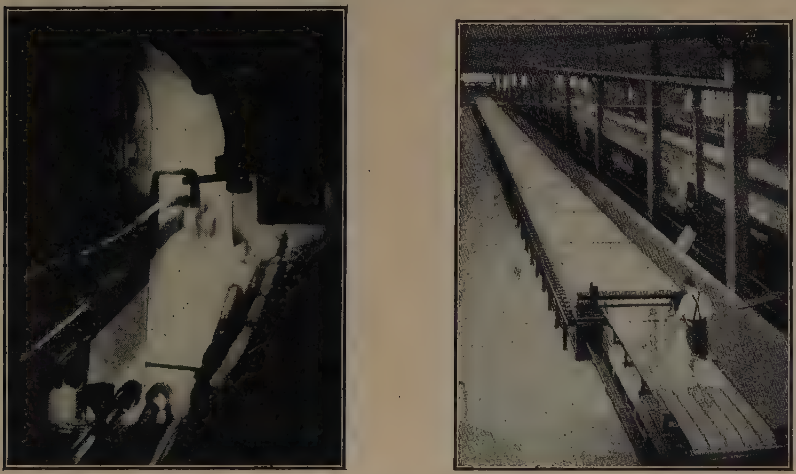


FIG. 250. — At left: A sheet of plastic glass rising from the drawing pot and passing over the bending roll to enter the annealing chamber. At right: Glass leaving the annealing chamber where it has been flattened and tempered to withstand changes in temperature.

with respect to natural light for that particular piece of work. Variations come at different times of day, with different seasons, and with different weather conditions, as is shown by the accompanying chart in Fig. 249.

Glass in the house. It is sometimes desirable to subdue direct light, or to pass some light through glass without making objects on the other side visible. This may be accomplished by various methods of surface treatment. The surface may be chipped, ribbed, ground by sand blast, or etched. Some colored glass permits a person on the dimly lighted side to see persons on the brightly lighted side, to whom the glass appears opaque. Many of these translucent forms of glass, and opal glass as well, diffuse light, and for this reason are also used as shades for artificial lights.

Window glass is made by drawing the molten glass into wide flat sheets. Just after the sheet of plastic glass leaves the drawing pot it

passes between water-cooled rollers which cool it enough to prevent it from changing its thickness as it is being pulled along. The glass may continue vertically until cut into sheets, or as shown in the illustration it may pass over a roller while still plastic and be flattened on horizontal tables and then annealed. Window glass made in this manner does not have the surface defects characteristic of that made by the older blown-cylinder process.

Plate glass is made by pouring the molten glass upon horizontal tables and rolling it out to the desired thickness. Its surfaces are then highly polished. Double-thickness glass sometimes has woven wire cast in it. This is used as a fireguard, since glass cracked by the heat will be held in place by the wire.

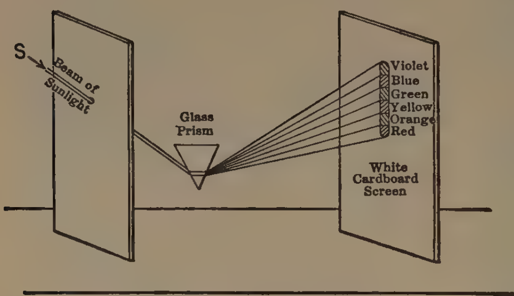


Fig. 251. — The solar spectrum.

Sunlight colors. The sunset red and the noonday blue, all the varied hues of the rainbow, the dull gray of a rainy day, and the brilliant white light are all sunlight. If a glass prism is placed in the path of a beam of light which enters a darkened room, it will throw a band of colors, called the **solar spectrum**, on the wall. White light, then, is a mixture of all these colors. We have already learned that light

TABLE XXI

Wave Lengths and Vibration Rates of Colors in the Solar Spectrum[1]

Color	Approximate Wave Length of Central Portion of Color Rays		Number of Vibrations per Second
	Millimeters	Ångströms[2]	
Red	0.00068	6800	441,000,000,000,000
Orange	0.00062	6200	484,000,000,000,000
Yellow	0.00058	5800	517,000,000,000,000
Green	0.00052	5200	577,000,000,000,000
Blue	0.00046	4600	650,000,000,000,000
Violet	0.00042	4200	714,000,000,000,000

[1] Visibility ranges from 7800 Ångströms for the red to 3900 Ångströms for the violet.

[2] One Ångström equals 0.0000001 mm.

consists of ether waves of various lengths, which distinguishes it from other radiant energy in the ether. Now we learn that light waves consist of many waves of different lengths. Waves of one particular length give one color sensation; waves of another length give a different color. Red, green, and blue differ merely in their vibration frequency and wave length. Red, at one end of the spectrum, has the longest wave length of light rays; violet, at the other end, has the shortest. All other colors have wave lengths intermediate between these two. The wave lengths and vibration rates of the six principal colors of the solar spectrum are indicated in Table XXI, page 274.

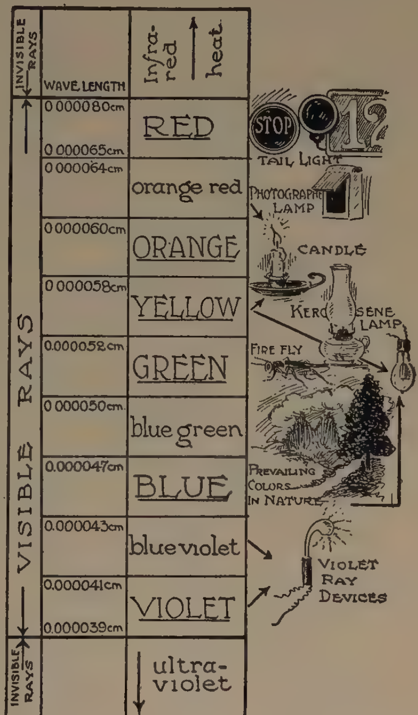


FIG. 252.—Distribution of light waves.

Color nomenclature. We find few pure colors in things about us; instead, there are mixtures of two or more pure colors. The dominant spectrum color in these mixtures is called **hue**. For example, the eighteen outer circles in the chart shown in Fig. 253 — *y, g–y, y–g, g, b–g,* etc. — are hues. Hues which lie opposite each other in this chart are *complementary,* and will, if mixed in equal amounts, neutralize each other and yield *neutral gray,* shown in the large central circle. The *intensity* (brilliancy, or chroma) of any hue may be dulled or softened by mixing a little of its complement with it. The *value* of a color is changed by mixing white or black with it, thus modifying its tone. A number of these tones in sequence form a scale of color. If white is mixed with a color, a *tint* results; but if black is mixed with the same color, a *shade* is produced. The hues from yellow through green and blue to the violet, including the various tints shown in the right-hand half of the diagram, are called *cool colors;* the shades and the hues from violet through red and orange to the yellow, shown in the left-hand half, are *warm colors.*

Color charts. Refer to Fig. 253. When each spectrum color is modified by an adjacent color, the resulting hue is designated in a way

to indicate the predominating color and the modifying color as well. For example, the mixture of a little green with blue gives *green-blue*, but the mixture of a little blue with green gives *blue-green*. The six spectrum colors and the two hues of each are represented on the outer circle. The neutral gray in the large circle in the center is produced

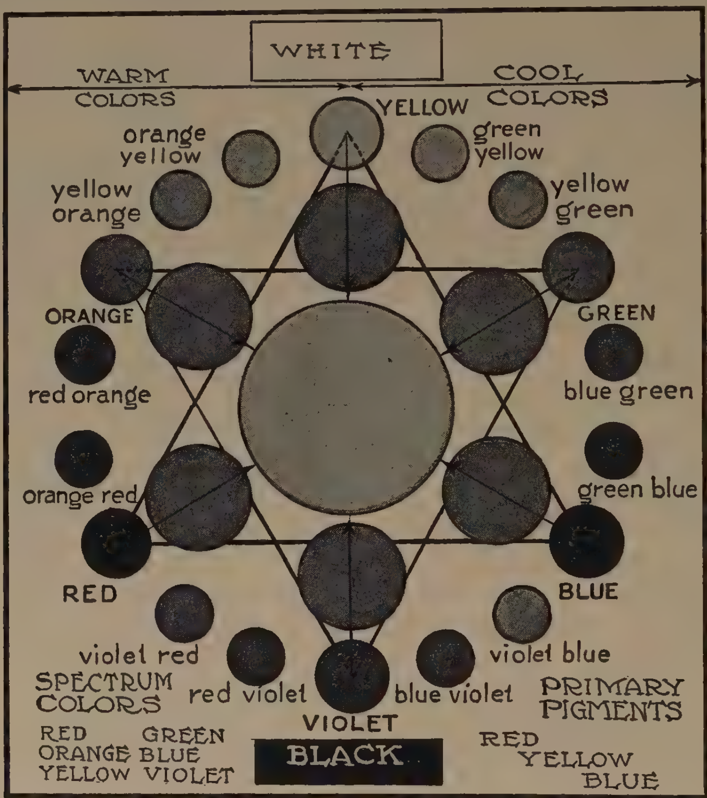


FIG. 253. — Color chart.

by mixing any two opposite (complementary) colors or by mixing all the colors. Each of the colors in the six large circles surrounding the central circle results from modifying the active color near it with a little of its complement. The best harmony of colors results from combining modified complementary colors.

Colored bodies. Objects that have the property of absorbing light waves of all lengths are *black*. Objects that have the ability to reflect light waves of all lengths are *white*. A red body is one that absorbs all the light waves except those producing the sensation of red. A blue body reflects wave lengths of blue and absorbs all others. Pieces of the

same cloth may be dyed different colors, because each of the different dyes has the power to reflect light of different wave lengths. Colored glass in white light transmits only the color due to the wave lengths that are not absorbed. A person wearing a blue dress enters a room whose windows transmit only red light, and the dress appears black. Why? What change would result in the appearance of a white collar? A "white" collar is one that in ordinary light reflects all wave lengths; but if it receives only the red waves, it can reflect only red waves and therefore it appears red. If you look through a deep green glass, white cloth looks green, green cloth looks green, black cloth looks black and all other colors as red, orange, yellow, blue, and violet look black also. You can readily understand this since the green glass can transmit only green rays and if there are no green rays which come to it no rays of any kind will be transmitted. The absence of rays of light produces black.

Color mixing. A mixture of all the colors coming from the sun gives white light. Make a blue spot on white paper, and an orange spot a few inches from it, and then view the two colors by means of a glass plate held vertically between them, so that one spot seen by reflection overlaps the other seen through the glass. White light results. Any two colors which, when mixed, give a sensation of white or gray are complementary colors. Mixing pigments, as paints and dyes, is quite a different matter from mixing colors (sensations). The physicist and the psychologist mix orange and blue colors, and white results. The artisan and the artist mix blue and yellow pigments, and green results. If a mark is made on the blackboard with blue crayon and a band of yellow is made over it, the result will appear green. A yellow pigment absorbs all spectrum colors except yellow and green, while blue pigments absorb all but blue and green. Green is the only color reflected by both pigments and is therefore the only color seen when the two are mixed.

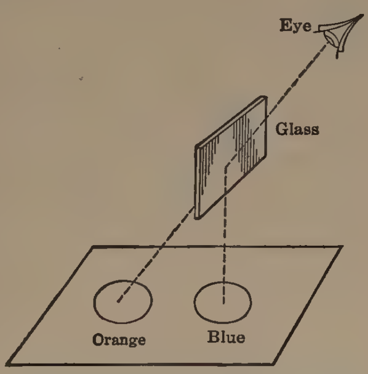


Fig. 254. — Complementary colors. Blue and orange give white.

Three-color printing. Color printing depends upon color mixing. Three colored inks, yellow, red and blue, are used. By the right mixture of these three pigments, any desired color can be produced. These three colors, because all other colors may be produced by them, are regarded as the **three primary pigments.** The plates for printing

each of these inks are made from photographs of the object taken through color filters. The color filter for each plate and the ink to be used on the plate are complementary colors. The print is made on white paper. First, the yellow is printed, then the red, and finally the blue is printed over the others. Certain parts of the picture receive only one color, other parts receive a mixture of two colors, and still other parts may receive all three. The proportion of the colors mixed must vary to produce colors different from those of the three inks. When skill and good judgment are exercised in selecting both color filters and inks, the colors of the original object photographed will be reproduced with great exactness.

Harmonious colors. Just as, in music, certain notes when sounded at the same time are harmonious, so, in light, certain color combinations appear harmonious to the trained eye. At the same time, certain other combinations of color are just as offensive to one who has been trained to know good color combinations as a discord of sounds. As one can be trained to appreciate harmonious sounds, so one can learn to recognize certain combinations of color which are harmonious. Complementary colors may always be used together, but the effect is more pleasing when the intensity of each pure color is modified by a bit of its complement. In nature, colors are as a rule modified, sometimes by mixture with other colors, sometimes by the atmosphere, and sometimes by reflection or from contrast with colors of near-by objects. In color arrangement these possibilities must be considered. Whenever a pure color is found in nature, it is small in extent compared with the dull or gray area. So in our use of colors, it is well to remember that a small spot of intense color will balance a large area of neutral color. The best color harmonies come from closely related hues, as yellow and orange, or from widely separated (complementary) hues, as yellow and violet, or red and green. When two colors near each other in the spectrum are used together, the effect is better if each one of them is modified by the addition of a little of the other, so that both of them, while having distinctly different hues, have a color in common. The color of the walls of a room may harmonize with the woodwork either by similarity or by contrast. Any color appears brighter against a black background and darker when it has a white background. Complementary colors give the strongest contrasts.

Reflection of light by fabrics. Smooth, shiny, fibers, like those of silk and rayon, reflect light without much diffusion; cotton, which has a flattened fiber, gives a highly diffused reflection. Wool diffuses light as does mohair, but the mohair fiber has the scales closer together than the wool and as a result it is more lustrous. Not only the material

but also the texture affects reflection. A smooth surface gives greater surface reflection of white light, whereas a rough surface, which reflects light that has penetrated the material, gives less white but more of the true color of the material. The reflection of white light from materials with high luster dilutes the colored rays. Wool and silk show greater differences in appearance from this cause than cotton, and for this reason colored cottons are easier to match. Silk velvets, however, show the least difference in appearance. This is because light penetrates deep into the fibers before it finds a surface suitable for reflection. Some materials are iridescent, displaying a variety of changing colors, much as does a very thin film of oil or tar on water, or the thin wall of a soap bubble. Reflection of light from two surfaces, one of which is slightly below the other, causes diffused waves which in places interfere with each other and so destroy the effect of the wave, while in other places they reinforce each other and thus intensify the color.

The rainbow. The rainbow is the result of a natural separation of sunlight into its elements, by the unequal bending of light waves of different lengths as they pass through drops of rain. The red rays are separated from the others and grouped together. In a similar way the orange, the yellow, the green, the blue, and the violet are each separated into a group by themselves. Sunlight is separated into colors by drops of water in accordance with the same principle that underlies the separation of sunlight by a glass prism. The series of colors produced is the solar spectrum, which has already been described.

SUMMARY

1. All ether waves are forms of radiant energy. The important forms of radiant energy from the sun are ultraviolet rays, light, and heat. When radiant energy is absorbed by matter, it is changed to heat. Radiant energy of the sun is absorbed to a considerable extent by the air. It is more intense at high altitudes than at low altitudes, for this reason.

2. Light rays changed to heat are trapped in a cold frame and put to practical use.

3. Houses should be so planned as to secure the most sunlight in the rooms that are most used. Regulation of natural light in the house is of much importance.

4. Sky light, or diffused sunlight, gives us a more even distribution of light and, for the greater part of the time, is the only light that enters our north windows.

5. The greatest poverty of natural light is found in the lower stories

of tall apartment houses separated by narrow streets. Prismatic glass in the windows helps to increase the amount of light received.

6. Glass may be made so that it will diffuse light and allow light to pass through, without making people or objects on the other side visible.

7. All sunlight is a mixture of light of many wave lengths. The mixture is white light, but the light resulting from any one wave length is color. The glass prism separates sunlight into a series of colors, called the solar spectrum. Red has the longest waves and violet the shortest.

8. The color of a body depends upon the length of the light waves that are reflected by it.

9. Complementary colors are those which, when mixed, produce white or gray.

10. Red, yellow, and blue when mixed give white. From these three colors all other colors may be produced. They are therefore regarded as primary colors or primary pigments.

11. Certain color combinations are harmonious; others produce color discords. The best color harmony results from the use of neutral colors either closely related or widely separated in the color spectrum.

12. The dominant spectrum and color of any material is its hue. The different values that result from mixing white or black with a color are called tones. When a color is mixed with white the tones are called tints, and when mixed with black they are called shades.

13. Smooth fibers, like those of silk, and smooth surfaces of cloth reflect light without diffusion, giving a white light which dilutes the real color. Flat fibers, like those of cotton, diffuse the light. Rough surfaces allow the light to penetrate, with the result that, when it is reflected, it discloses more of the true color of the cloth.

14. The rainbow results from the separation of sunlight into colors by refraction and reflection.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Daylight in my house.
2. Rainbows.
3. Mirage.
4. Color harmonies in the home.
5. Test color mixing: with the color wheel; with pigments.
6. Glass making.
7. Planning the orientation of a house.

CHAPTER XIX

ILLUMINATION

The eye. In its essential parts, the eye resembles a camera, having a shutter (eyelid), diaphragm (iris), lens (crystalline lens), and sensitive plate (retina). The amount of light that enters the eye depends upon the opening in the iris, which is automatically regulated. The

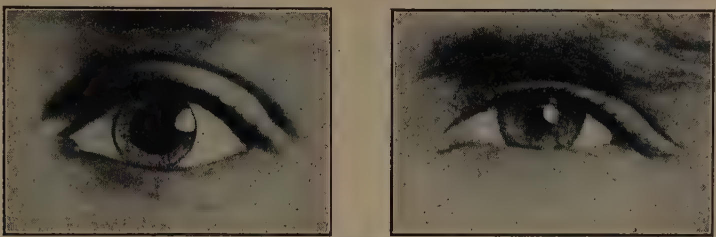


FIG. 255. — The size of the pupil adjusts itself to the intensity of light.

shape of the lens, too, is controlled by delicate muscles which cause the thickening and flattening of the lens, thus shortening and lengthening the focus, as near and far objects are viewed.

In going from a dark to a light room, the iris immediately begins to contract, shutting out the excess of light. Similarly, in going into a dark room from a light one, the iris opens to admit more light. For the same reason, when a person is moving about in a room that is very unevenly lighted, the muscles controlling the iris of the eye are constantly active, adjusting the eye to the varying conditions of light intensity. These muscles may thus become tired and eye fatigue may result.

The brightness of the average white sky ($2\frac{1}{2}$ candlepower per square inch) is the brightest natural light to which the eye is habituated through long experience. An intensely brilliant light, therefore, causes the eye to protect itself by such an excessive contraction of the iris that proper vision is possible only through great eyestrain, which, if continued, may work permanent injury. Our eyes are protected by protruding bone and the eyebrows from light coming from above. The eye has no such protection, however, from light directly in the line of vision or coming from below, and, therefore, an intense light in either of these positions produces an effect known as *glare,* which, if continued,

may prove very injurious. From the preceding statements it will be apparent that a proper intensity of illumination and a correct placing of the lights in a room are of great importance.

Development of artificial lighting. The earliest account of man's using artificial light describes his burning wood and using the pitch knot for a torch, some six thousand years ago. Following this, resins and pitch were extracted from wood and burned. Many years before

FIG. 256. — Six thousand years of progress in lighting from the pitch knot to the kerosene lamp.

Christ, vegetable and animal oils were a source of light. Tapers and lamps with wicks date as far back as the building of the Pyramids, and there was no important advance in the manufacture of these lamps until the nineteenth century. Candles were made two or three thousand years ago, and were common all through the Middle Ages. As late as 1834, the English House of Commons was lighted by candles. In this country, sperm oil and candles were the chief sources of artificial light, up to the time of the Civil War. Petroleum was discovered in Pennsylvania just before this, and it rapidly displaced the whale oil, which, owing to the scarcity of whales, had increased in price from 80 cents to $1.77 a gallon; kerosene was soon reduced in cost to 55 cents a gallon. A candle costing 2½ cents would burn for seven hours. It is an interesting fact in the history of lighting that Cicero and Lincoln were dependent upon practically the same means of artificial light, no important improvement in methods of lighting having been made in all the intervening time.

By 1875, kerosene lamps had been improved to such an extent that tallow candles ceased to be important sources of light. Gas was used to some extent in cities, but cost $2.50 per 1000 cubic feet. By 1895, kerosene oil had dropped to 13½ cents a gallon and gas to $1.50 a thousand. Just before this, the first important improvement in oil lamps was made: the flat wick was replaced by a round wick with a

central draft. The glass chimney was also in use at this period. At this time electricity and the Welsbach gas light were the chief light sources for cities.

At the present time we find little gas used for lighting but electric lighting has increased greatly. The amount of light used by the average thrifty family today is nearly fifty times that used one hundred years ago.

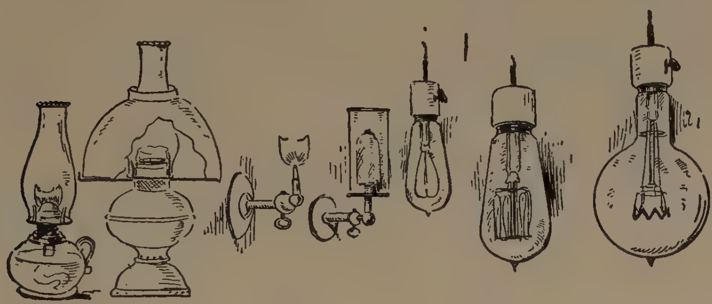


FIG. 257. — Fifty years of progress in lighting from the kerosene lamp to the electric tungsten lamp.

Units of light measurement. The unit of light intensity at its source is the **standard candle.** Actual standard candles are little used now, but the value of a candlepower is established by standard incandescent lamps. The candlepower of any light source may be determined by comparison with this standard lamp. The process is known as *photometry,* and descriptions of the apparatus and method may be found in any standard reference book on this subject. In the home we are more interested in the *intensity of illumination* at a given place than we are with the candlepower of the light itself, although there is, to be sure, a relation between the two. The **foot-candle** is the intensity of illumination given by a standard candle at a distance of 1 foot. If a standard candle is in the center of a dull black spherical box 2 feet in diameter and an opening having an area of 1 square foot is cut in it, the light that passes out through the opening is 1 lumen. Likewise, if we were to place a candle 1 foot away from a square foot area, the light falling upon the square foot would be 1 lumen. Briefly stated, the *lumen* is the intensity of 1 foot-candle upon an area of 1 square foot.

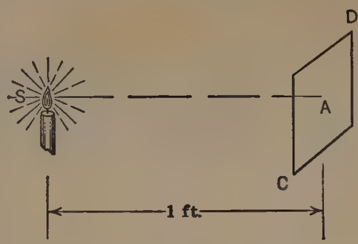


FIG. 258. — The illumination at *A* is 1 foot-candle.

Intensity of illumination and distance. It is a matter of everyday experience that the nearer we hold our book to the light the more intensely it is illuminated, and yet few people can tell you how much more brilliantly it is lighted when it is moved one, two, or more feet nearer to the light.

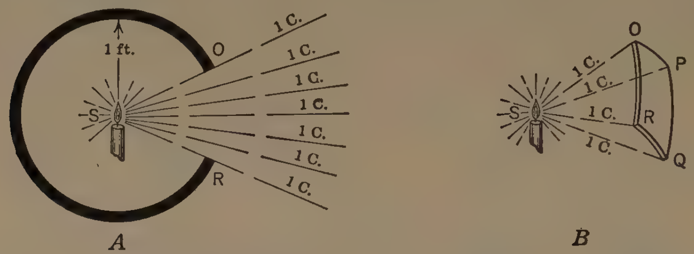


Fig. 259. — (*A*) The opening *OR* has an area of 1 square foot and allows 1 lumen of light to pass. (*B*) One lumen falls on surface *OPQR*, which has an area of 1 square foot, all points of which are 1 foot from the candle.

In a dark room, cover a lamp with a metal chimney which has a pinhole on one side. At a distance of 1 foot, place a screen of cardboard having a hole 1 inch square in it. The light coming through this 1-square-inch area will light an area of 4 square inches on a screen 2 feet from the light. Evidently the same quantity of light falls on the 1-square-inch area at 1 foot distance as would fall on a 4-square-inch surface at 2 feet distance. Hence each square inch at 2 feet receives one-fourth the light that a square inch receives at 1 foot distance. If we move the second screen to a place 3 feet from the light, 9 square inches will be lighted, and the intensity of light will be one-ninth of that at 1 foot. This is stated in the **law of inverse squares:**

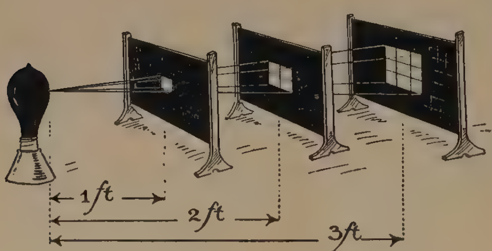


Fig. 260. — The intensity of illumination at 3 feet is only one-ninth that at 1 foot from the light source.

Other conditions being the same, the intensity of illumination upon any surface varies inversely as the square of its distance from the light.

Other causes of variation in intensity. The intensity of illumination at any distance varies directly with the intensity of the light source. The intensity of illumination also depends upon the angle between the surface and the rays of light. The greatest intensity is found when the

surface is at right angles to the rays of light. *AB*, *AC*, and *AD*, Fig. 261, are all equal surfaces, but *AD* receives only about half the light that *AB* receives. This is the same principle that is involved in explaining why the slanting rays of the sun give us less heat and light than the vertical rays, even in spite of the fact that the sun is several millions of miles nearer to us at the beginning of winter.

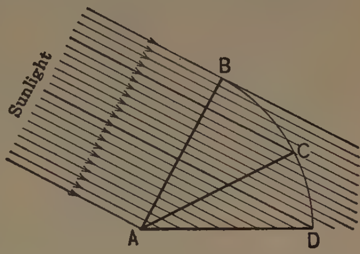


Fig. 261.—The intensity of illumination depends upon the angle at which a surface meets the rays of light.

Electric lamps. Where electricity is available it is the most used illuminant. One's distance from the lamp is important. At 1 foot from a 60-watt table lamp there are about 80 foot-candles, but at 2 feet there are only 20 foot-candles. A 100-watt lamp gives about 150 foot-candles at 1 foot distance and a fourth of that or just under 40 foot-candles 2 feet away.

If all the electrical energy could be transformed to white light, it would be equivalent to 300 lumens per watt, but, instead of this much-desired 100 per cent transfer, in practice the 100-watt Mazda lamp gives out only from 7 to 10 per cent of the electrical energy as visible light. Smaller lamps give less than 7 per cent, and larger ones may transform more than 10 per cent of the electrical energy consumed into light. In order to give out 38 lumens per watt, the filament would need to be above 6100° F., or so hot that the tungsten filament would melt.

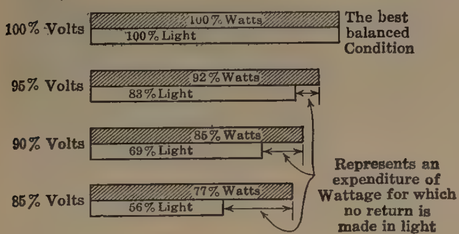


Fig. 262.—Electric energy is wasted when a lamp is used on a circuit giving lower voltage than that marked on the bulb.

In Chapter XVI it was stated that lamps should be used at the voltage marked upon them. If the voltage used is only 85 per cent of that marked on the bulbs, the wattage consumed is 77 per cent, but the light is only 56 per cent of that when the proper voltage is used. (See Fig. 262.) When the voltage is higher than that marked on the lamp, the lamp burns out quickly; when the voltage is lower, the lamp gives too little light for the amount of electrical energy consumed.

Large recreational areas, as for baseball, football, or other purposes, generally used 1000- or 1500-watt lamps. If these can be operated at 10 per cent over voltage, there will be a gain of 35 per cent in light with

only an increase of 16 per cent in wattage. The life of the lamp will be reduced to 300 hours, but the initial installation of lighting equipment will be substantially reduced.

Three-light lamps. The three-light lamps have two filaments which may be lighted singly or together. These may be 100 watts and 200 watts. The lower wattage is for table lamp and decorative use but also gives much useful light. The higher wattage is for the new-type floor lamp, which is particularly good for study or reading. The

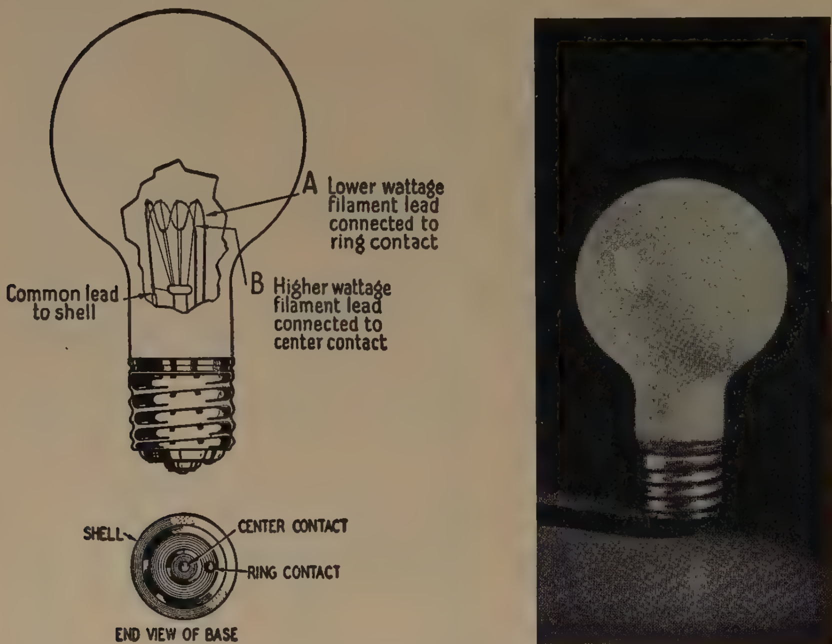


FIG. 263. — The three-light bulb has two separate filaments. The 300-watt lamp has a 100-watt filament and a 200-watt filament. A special socket is required for this lamp.

diagram shows how the two filaments have separate contacts. When the 100 and 200 filament lamp has the switch turned for high power both filaments are connected and 300 watts are used.

The table and floor lamps. When a table lamp is used, the rest of the room ought to be moderately lighted to prevent sharp contrasts when the user looks up. The sudden adaptation required on glancing from lighted to dark areas is harmful, particularly if frequently repeated. Sharp contrasts may be prevented by using other lights; by having semi-transparent shades, not too dark; or by having an opening at the

top of the shade, allowing direct light to pass unobstructed to the ceiling, where it may be diffused to shed a soft light throughout the room. The position of the table lamp with respect to the reader is very important. It should never be directly in front so that light from the page is reflected upward squarely into the eyes.

The six-way lamps are well adapted to give light to satisfy a variety of conditions. The large lamp has two filaments; one of 100-watt

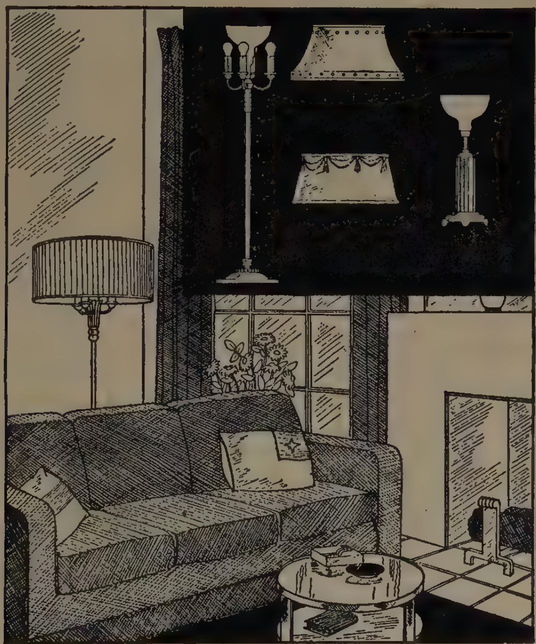


FIG. 264.—Floor and table lamps. A three-light bulb in open-top diffusing bowl with three outside small "candle" bulbs can give fifteen lighting values. Can you figure out how this can be done?

and the other 200-watt capacity. Either can be used alone or when both are on it gives the equivalent of a 300-watt lamp. Besides this there are three sockets into which lamps of any desired wattage may be placed. These may be turned on singly or in combination and may be added to the large lamp if desired. If the small lamps are 60-watt what combinations of wattages can you get?

How much light do we need? The intensity of light that is desirable in the various rooms of the home is shown in Table XXII. These lighting intensities are at best only suggestions. The intensity of illumination is the same, regardless of the material upon which the

light falls, but brightness of the object due to the light it reflects varies greatly. White cloth, black paper, and a colored post card send very different amounts of light to the eye. It is not so much the intensity of illumination as the amount of light that reaches the eye that counts. It has been found that satisfactory conditions for seeing

Fig. 265. — The greater the distance from the source of light, the fewer the foot-candles of illumination.

exist when from 1 to 2 foot-candles reach the eye. If an object reflects only 20 per cent of the light it receives, it must receive at least 10 foot-candles to give the eye 2 foot-candles, but, if it reflects only 10 per cent of the light, it must receive 20 foot-candles. The illumination needed in a given room varies with the occasion and the particular use to be made of it, a softer and lower illumination being appropriate when conversing than when studying maps or reading. The average newspaper reflects fully half the light it receives, but a black cloth

may reflect only 5 per cent of the light. It is a good plan to have fixtures and switches so placed that certain lamps may be turned on independently of others in the same room.

Steadiness. A flickering light quickly causes eyestrain by calling upon the eyes for continual readjustment. Our usual forms of lighting give little trouble of this kind. The effect of a flickering light is produced when one reads in a moving car. This requires repeated and rapid readjustment of focus. The result is eye fatigue. Much reading under such conditions should be avoided.

FIG. 266.—The modern luminaire (at the right) giving diffused light is much easier on the eyes than the old-time lamp at the left. The antiquated reflector makes a glare on the table and leaves the rest of the room in semi-darkness.

Proper lighting. Home lighting should meet the following fundamental requirements:

1. It must provide enough illumination for required use.
2. It must be of color satisfactory to required use.
3. It must give a steady and diffused light.
4. It must not produce glare either from shining directly into the eyes or by reflection from a glossy surface.

To these requirements should be added the desirable qualities that the light should be dependable and should have low cost.

Illumination. The usual commercial and industrial need for illumination varies from 1 foot-candle to 25 foot-candles, and in some special cases even more. In the home the usual need varies from 1 to 10 foot-candles, but if sewing or other fine work is done, 25 or more foot-candles may be needed.

It is not true that *more* light is always better. There is a limit beyond which an increase in illumination does not aid vision; such excess of light not only is wasted but also, if the source is within the field of vision, may be injurious to the eye. The intensities suggested

TABLE XXII

RECOMMENDED LIGHTING INTENSITIES FOR THE HOME
(Approved by the Illuminating Engineering Society)

	Foot-candles
Reading	
Prolonged periods with fine type	20–50
Ordinary reading	10–20
Sewing	
Fine needlework on dark goods	100 or more
Prolonged average sewing	50–100
Prolonged sewing on light goods	20–50
Ordinary sewing on light goods	10–20
Writing (ordinary)	10–20
Card playing	5–10
Children's study table	20–50
Dining room (when used for ordinary reading or writing)	10–20
Kitchen	
General	5–10
Local at work counters and sink	10–20
Bedroom	
General	2–5
Bed light	10–20
Dresser, vanity, and dressing-table mirrors	10–30
Sewing machine	20–50
Bathroom mirror	10–30
Children's playroom	
General	5–10
Local	10–20
Stairways and stair landings	2–5
Workbench	10–30
Ironing machine, ironing board, and laundry trays	10–20

in Table XXII average higher than we find in the average home and which are found to be satisfactory to most people. Older people generally need more light than younger people.

Quality. All our common artificial lights, when compared with sunlight, are found deficient in blue and violet rays. This can be considered a disadvantage only in the effect such a light has upon colors. Under most artificial light, blues and purples appear black, and green may appear blue, but reds and yellows show up in their proper colors. The reds and yellows, which predominate in artificial lights, are generally considered more restful to the eye, and it is believed that they promote cheerfulness more than light of shorter wave lengths. The red and yellow wave lengths have great penetrating power; this is seen in observing the sun through a fog or haze. It is for this reason that a red light is used as a danger signal on boats and railroads; it can be seen through smoke and steam better than a blue light.

Daylight lamps. A new fluorescent lamp which gives daylight values is available for home use. Instead of bulbs with filaments, cylindrical tubes are used. The tubes have a partial vacuum inside. In starting, a little mercury is vaporized. A high-pressure electrical discharge produces ultraviolet rays. The tubes are coated on the inside with chemicals which glow when excited by ultraviolet rays.

The new lamps may vary from 18 inches to 3 feet in length. A small transformer will change the present 110- to 120-volt alternating current to the proper voltage for the length of tube used. There is no appreciable heating effect, and consequently the lamps are very efficient in transforming electrical energy to light energy. The initial cost of lamps, at present, is much greater than for the bulb lamps.

Glare. One of the most important conditions required in good lighting is proper diffusion. Without diffusion, glare results. Many people suffer from glare produced by brilliant lights, and they think there is no remedy for it. A strong light against a black background causes much greater discomfort to the eye than the same light against a white background. In rooms where people spend much time, there should be no strong contrast of light upon which the eye may rest.

Two types of glare to be avoided are **direct glare,** in which light reaches the eye directly from the source of light, and **reflected glare,** which results when some smooth or shiny surface reflects strong light directly into the eyes. Bare lights at eye-levels are particularly harmful. Shades or diffusing globes should be provided to prevent the light from shining into the eyes. All frosted — sand and acid etched — opal and ribbed globes reduce the intensity per square inch by increasing the size of the visible source of light. Frosted lamps are preferable to unfrosted ones.

The effect of glare in diminishing the visibility of near-by objects is clearly demonstrated as follows: Cut a 6-inch hole in a large sheet of cardboard; print 2-inch figures about the margin of the cardboard, and around the edges of the hole; cover the hole with wax paper. In a dimly lighted room, observe that the letters near the hole and far from it are read with equal ease. Place a lighted 100-watt lamp behind the wax paper. A strong diffused light passes through the paper, causing the iris to reduce the opening into the eye. All the letters are less easily read than before, and those close to the hole are much more indistinct than those at a distance from it.

An objectionable glare frequently results when light is reflected by glossy paint, glossy paper, and the glass of pictures. Coated papers, capable of reproducing half-tone pictures, are now available, and should replace the common glossy paper, since they give much less trouble from

glare. The means of preventing glare is diffusion, preferably near the source of light. Notice the absence of shadow in Fig. 267B. This lamp reflects the light up into the reflector above, which gives out a pleasing, diffused light. With diffusing bulbs, such as the bowl-enameled, bowl-frosted, and all-frosted, a small amount of light is absorbed, but there is a big gain in one's ability to see clearly.

A

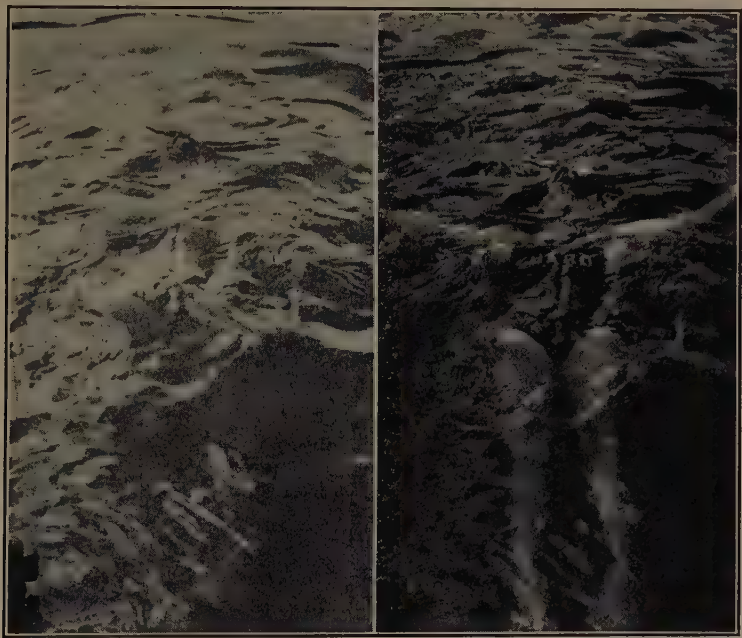
B

Fig. 267. — *A*. Lamp with clear glass gives harsh shadows and much glare. *B*. Bowl-frosted lamp. Notice the absence of sharp shadows and glare.

Non-polarized light — our usual light — is made up of waves which vibrate in all directions. The up-and-down waves penetrate the surface of a body, and the reflected beam discloses the surface condition. It is these rays that are useful in our reading and on our work. The side-to-side rays are reflected without penetration much as a stone thrown nearly horizontal with the surface of water skips along the surface. These side-to-side rays produce most of the glare. Polaroid

film allows vibrations in only one plane to pass through. It can be held so that it will permit the up-and-down waves to pass but will shut out the side-to-side waves. In this way it acts as a selector of rays and shuts off all glare. Polaroid glasses are available to reduce glare.

Shades and reflectors. It frequently happens that a lamp gives but a small part of its light in the place where it is most wanted. It is therefore desirable to redirect some of the light, and perhaps to soften it in some directions. The shade helps to darken portions of the room, and the reflector redirects light into places where it is needed. Shades and reflectors may protect the eyes and if chosen for their artistic qual-



Photographed by Life Magazine.

Fig. 268. — Polaroid film reduces glare. Both pictures were taken at the same time. The one at the right was taken through a Polaroid filter.

ities, they give a decorative effect. Opaque reflectors are less pleasing than those which allow some light to pass through. Opal glass and frosted glass are commonly used when a white shade or reflector is desired. Colored or stained glass and colored silk offer an opportunity for selecting shades that harmonize with the other room decorations. All these should permit enough light to pass through to prevent gloomy shadows, unless there are other light sources to light the rest of the room.

The effect of rough surfaces and semi-transparent material for shades, in producing diffused light, is shown in Fig. 269. A rough surface, such as frosted glass, diffuses light by refraction, and semi-transparent glass, such as opal glass, diffuses the light through reflection and refraction.

Efficient lighting. Efficient lighting requires that attention be given to the particular needs of a given place and that those forms of lighting which will serve these needs be chosen. The efficiency of a lighting unit is *the ratio of the light given out from the luminaire* to the light at the source.* The selection of lamp shade and reflector is important in this connection. Every time a ray of light is reflected, some of it is lost by absorption. A reflector that sends a ray back and forth several times before it escapes is therefore wasting light.

Dust on the reflectors and shades used in semi-indirect lighting reduces the effective lighting power sometimes 25 to 50 per cent. The general

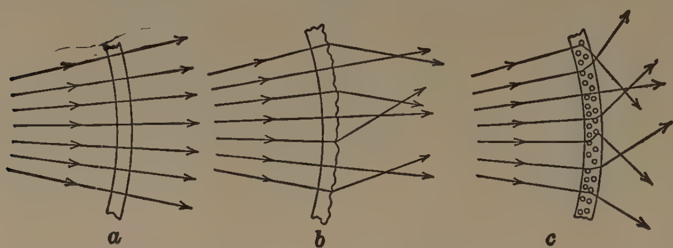


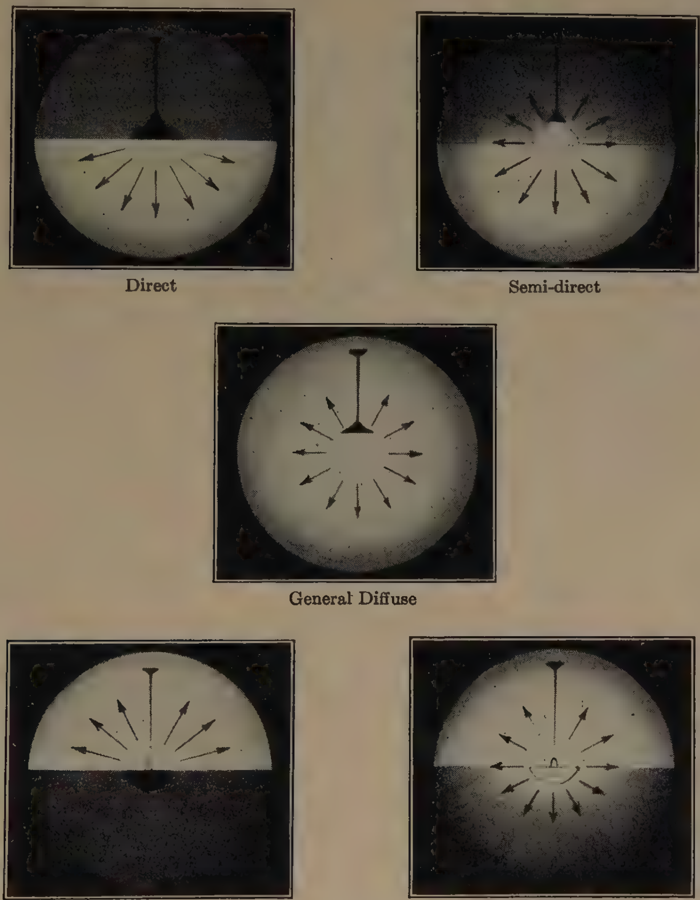
FIG. 269. — Transmission of light. (*a*) Clear glass. (*b*) Frosted and etched glass. (*c*) Opal or milk glass.

tone of the walls and furnishings has a marked effect upon the amount of useful light we get from any lighting source. Old, blackened electric bulbs should be replaced by new ones.

Types of lighting. We have come to recognize, in recent years, five types of lighting, which are distinguished by the manner in which the light is distributed. In the first of these — **direct lighting** — light comes directly from the source to the place where it is used. There is a shade or reflector to throw the light downward in a useful direction. If the lamp has a clear glass bulb or globe, conditions are favorable for glare by reflection from a glossy surface. This is the least expensive of the five types as far as cost of lighting is concerned. In the end, however, the eye fatigue and strain which result may cause it to be an expensive type of lighting. Luminaires of the **semi-direct** type have shades which allow some light to pass upward. This helps to reduce

* *Luminaire* is a term designating a lighting unit and includes fixture, lamp, and shade or globe.

dark shadows which make a room very gloomy. **General diffuse lighting**, a third type, is produced when the light is enclosed within a diffusing globe of opal glass. The diffusing globe should not allow the lamp bulb to be seen through it. Light radiates from it in all directions.



Direct — Semi-direct — General Diffuse — Indirect — Semi-indirect

Fig. 270. — Types of lighting.

Luminaires of this type provide light which is reflected from upper walls and ceiling.

Indirect lighting is produced when all the useful light in the room is obtained by reflection of light from concealed light sources by the ceiling and walls. The concealing device is often an opaque reflector, by which those rays which would naturally come directly into the room are sent to the ceiling, where they are reflected and diffused. This gives a very

soft, evenly distributed light throughout the room. This light is much like daylight in its general effect, and it is very restful to the eyes, though some people object to the sharp contrast between the opaque reflector and the brilliant ceiling against which it is seen. This type of lighting is the most costly, because a large part of the light is lost by absorption. When it is used the ceiling must be kept in good reflecting condition. It should have a matte finish of high reflecting power. Lamps and reflectors must be kept clean. A thin layer of dust has a surprisingly large absorption power. Inside-frosted lamps are recommended.

Semi-indirect lighting differs from indirect lighting only in substituting a translucent shade for the opaque reflector of the indirect type. The reflected light from the ceiling mingles with the diffused light which shines through the shade. As you would expect, this gives a soft, diffused light. It is intermediate in cost of operation, and is a type which can be recommended for general house lighting. Semi-indirect luminaires may vary from one with a dense shade, which is very close to the indirect type, to one with a very thin shade, which closely approaches the direct-lighting type. One type of luminaire for semi-

TABLE XXIII

DISTRIBUTION OF LIGHT IN DIFFERENT TYPES OF LIGHTING

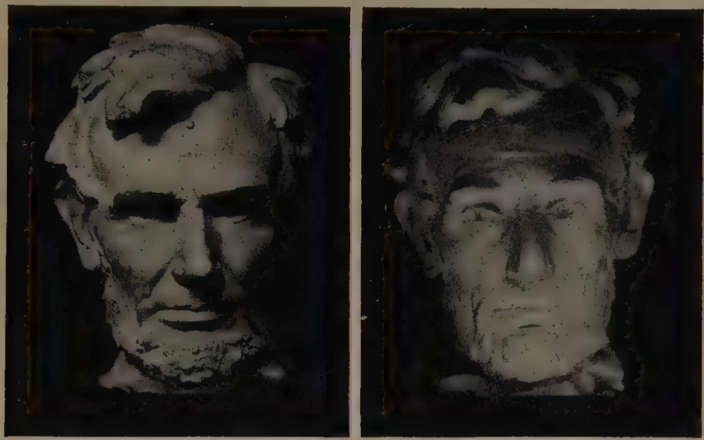
Classification	Approximate Distribution Luminaire Output	
	Per Cent Upward	Per Cent Downward
Direct	0–10	90–100
Semi-direct	10–40	60–90
General diffuse	40–60	40–60
Semi-indirect	60–90	10–40
Indirect	90–100	0–10

indirect lighting is an enclosed globe, whose lower part is white reflecting and diffusing glass, and whose upper part is transparent, so that much light goes to the ceiling where it is diffused.

The amount of light sent upward and downward by each of the types of lighting as determined by a committee of lighting engineers is shown in Table XXIII.

Light and shadow. Harsh shadows in a lighted room are objectionable. On the other hand, uniform light throughout the room is just as bad, because, without some contrast of light and shade, objects

seem to lose their form, and look unreal. Soft shadows are restful to the eye. Well-illumined shadows upon our work make form and detail easier to distinguish. Art objects, as statuary and pictures, may be grotesque when improperly lighted. This is forcefully shown in the photographs of the bust of Lincoln. The same piece of statuary was



Courtesy General Electric Co.

FIG. 271.— A piece of statuary may appear ugly or pleasing according to the distribution of light and shadow, which can be controlled by the manner of lighting it.

photographed under different arrangements of light. Shadows which are like those produced in nature bring out a lifelike appearance; but the reverse shadows destroy this pleasing effect.

Good lighting practice. If both strong shadows and equal lighting of all surfaces give unsatisfactory lighting, what is good lighting practice? Natural lighting gives us the answer. Under natural, out of door illumination, the light from a clear sky received upon a horizontal plane is about one-third that received directly from the sun. Hence it would appear that, if we have our indoor illumination in the same ratio, we shall secure satisfactory lighting. Light from a single lamp, unless diffused light is mixed with it, gives intense, black shadows. But if objects in the room receive one-third diffused light and two-thirds direct light, there will be shadows, but shadows free from strong contrast and therefore pleasing and without discomfort to the eye.

Importance of wall and ceiling surfaces. One may select the right size, number, and location of lamps for lighting a room and yet fail to secure good results because of the walls and ceiling.

The interior finish of walls and ceiling is a factor in efficient lighting. Woods in natural finish may give from about 15 to 50 per cent reflection of light. There is a greater range from wall paints. As much as 85 per cent may be secured by a very light, almost white wall; 70 to 75 per cent for cream; 35 to 50 per cent for light greens; 55 to 65 per cent for yellow, and down below 10 per cent for dark shades. Dull surfaces diffuse the light and are preferable to gloss because they reduce glaring reflections. The surfaces of the room are in reality secondary sources of light, and the effective illumination in a room depends very largely upon the reflection of light from them. The warmer colors as cream or buff make a room look smaller. Cool colors as light blue or green make a room seem large.

The upper walls may be light colored; but the lower area, within the common range of the eye, should be a darker, neutral color in order that the eye may rest in comfort upon it. One should, however, guard against using too dark wallpaper. Exhaustive tests have been made of the reflection from walls and ceilings of various colors and surfaces, and the data of these tests may be found in handbooks on illumination or obtained through decorators and dealers in lighting supplies. Consideration of these data is well worth while when planning the decorations for the home.

SUMMARY

1. The eye has wonderful power to adapt itself to light of different intensities. The iris reduces the size of the pupil as light increases and enlarges it when the light decreases. The eye endures the hundreds of foot-candles that are present in sunlight, and one can read in a fraction of a foot-candle of illumination.

2. The intensity of light we need depends upon what we are doing. Two and one-half foot-candles give good general illumination, but for sewing on dark material 25 foot-candles are not too much. An intense light in the field of vision is exceedingly harmful. The eye should always be protected against direct glare as facing a bare light and against indirect glare resulting from reflection from a glossy surface.

3. Proper lighting is sufficient in amount and good in quality, and gives no glare or sharp contrasts. It must be steady and dependable, and should be inexpensive.

4. Artificial lights are deficient in colors toward the blue end of the spectrum. By using a blue glass or a blue-green filter, the reds are absorbed to such an extent that the light which results approaches daylight in quality.

5. A proper distribution of light and shadow is important as it determines in a large measure the appearance of objects.

6. Shades and reflectors are of value in softening and redirecting the light to protect the eyes from glare or contrasts, and to give more light in places where it is needed.

7. Efficiency in lighting is secured by having the proper globe fitted to a lamp, by keeping the dust off the globe, shades, and reflectors, and by selecting proper tones of ceiling, walls, and furnishings.

8. In direct lighting the light comes directly from the lamp to the work, without being reflected or diffused. In indirect lighting an opaque reflector throws all the light to the ceiling or walls, from which it is diffused into the room. In general diffuse lighting, light is diffused in all directions.

9. The walls or baseboards of the house should be provided with a number of electric outlets, to which various electrical conveniences or extra lamps may be attached.

10. Considerably less than a century ago, there was no better source of artificial light than the candle or the flickering oil lamp.

11. Intensity of illumination varies inversely with the square of the distance. It varies directly with the intensity of the light source.

12. One candlepower is the light given by a standard candle. A foot-candle is the intensity of this light at a distance of 1 foot from its source. The lumen is the intensity of 1 foot-candle upon 1 square foot of surface.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Glare — its evil effects and the remedy.
2. Pleasing and efficient home lighting.
3. Determine the illumination in the home with a foot-candle meter.
4. Determine, by test with a foot-candle meter, the effect of dust on reflectors and shades.

CHAPTER XX

VISUAL AIDS

Sight-aiding devices. Civilization has brought many problems, not the least of which are those which relate to better vision. We of today have many needs not known to people of the remote past. Science and invention have well provided for the needs of civilized man in meeting his new and larger problems. This is particularly true in the field of sight-aiding devices. Where is there a home today that cannot make a good display of such devices? There are the reading glass or a simple magnifying glass; the eyeglasses or spectacles; the opera glass and field glass; the stereoscope; the telescope or spyglass; the camera, perhaps a toy periscope, and possibly a " bull's-eye " lantern.

Thanks to science, we can, by using the proper instruments, see some of the unseen. Bodies remote from the earth, invisible to the naked eye, are brought within our range of vision. Near-by bodies, so small that they cannot be seen, are enlarged until they are visible. Defects of the most important optical instrument of all to mankind, the eye, may be remedied by means of artificial devices. In all these instruments and devices, the most important part is the lens.

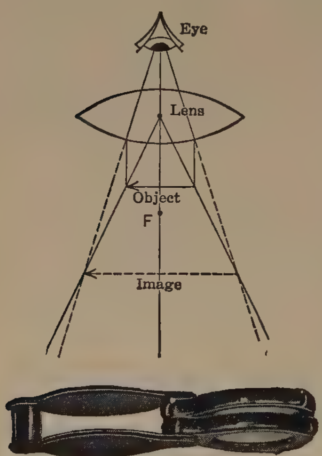


FIG. 272. — A simple microscope and how it makes an image larger than an object.

The reading glass. The reading glass is a form of simple microscope with a long focus. The microscope lens has a greater curvature and shorter focal length than the reading glass. In both the reading glass and the small microscope, the object to be seen must lie between the lens and the principal focus. The microscope must be much nearer to the object than the reading glass, because of the shorter focus of the microscope lens. The diagrams of Figs. 272 and 273 show why the image is larger than the object.

We judge the size of a body largely by the angle made in the eye

between the rays of light from the extreme ends of the body. By bending the rays of light, the lenses of the reading glass and microscope increase the angle at which the rays of light from the object enter the eye. In this way an enlarged image is produced.

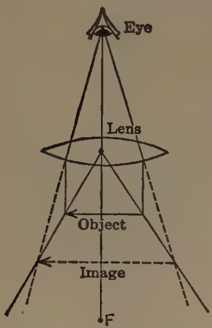


FIG. 273.—How the reading glass magnifies.


FIG. 274.—The reading glass is a simple microscope.

The compound microscope. Two lenses are used in the compound microscope. The smaller of these has a short focal length and is called the **objective**; the larger is the **eyepiece**. When the microscope is focused for use, the object is placed at a distance greater than the focal length and less than twice the focal length of the objective. A real, inverted, and enlarged, image is produced at some place between the two lenses. This image must also lie between the eyepiece and its principal focus. The eyepiece thus acts as a simple magnifying glass and magnifies the enlarged image of the object. This double magnifying process makes it possible so to enlarge many invisible bodies that they may be seen. A study of Fig. 275 will make clearer how the compound microscope works.

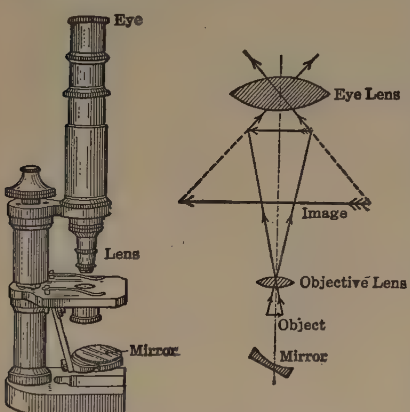


FIG. 275.—The compound microscope.

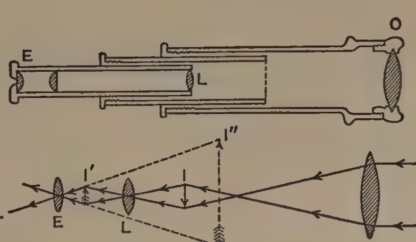


FIG. 276.—A refracting telescope for common use.

Telescopes. There are two types of telescopes, **refracting** and **reflecting.** The refracting telescope has at least two lenses. The objective has a large diameter to admit much light, and it has a long

focus. The eyepiece is small and is used as a simple microscope to magnify the image produced by the objective lens.

The object is at a greater distance from the objective than twice its focal length; hence the image is smaller than the object. It is inverted and real. The image is magnified by the eyepiece sufficiently to make it appear larger through the telescope than to the naked eye. In the astronomical telescope the image seen is inverted. For land use an

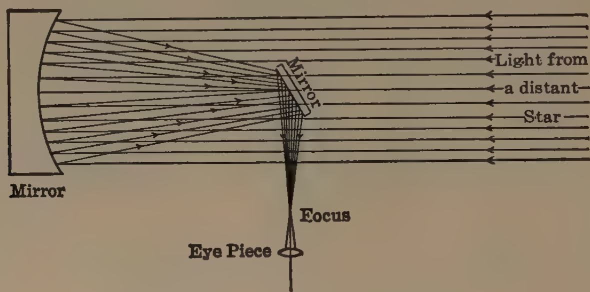


Fig. 277. — A reflecting telescope.

extra lens is placed within the barrel of the telescope, in order that objects may appear right side up.

The reflecting telescope makes use of a large concave mirror to collect a great amount of light which is conveyed to form a real image. This image is viewed through the eyepiece lens. The advantage of the reflecting telescope is that the reflecting mirror can be many times the size of the refracting lens and can therefore produce a more brilliant image to be enlarged by the eyepiece. It is expected that the new 200-inch reflector being installed at Mount Paola will collect enough light from stars not yet discovered to make them visible and thus add to our knowledge of the heavens.

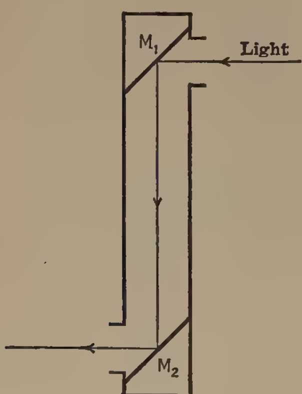


Fig. 278. — A simple periscope.

Both types of telescopes are used to photograph the heavenly bodies. Stars which cannot be seen through the telescope, because the light is too faint to affect the eyes, can be recorded on a photographic plate because of the long time of exposure.

The periscope. A simple periscope requires only two mirrors, facing and parallel to each other, placed some convenient distance apart and at an angle of 45° to the line of sight.

For protection, it is better to have the mirrors inside a hollow tube, with openings properly placed for the passage of light from the object to the eyes. Field glasses may be used instead of direct vision. Except as a toy, the periscope is of no use in the home, but in the submarine and in the trench it is invaluable in war. Right-angle prisms may be substituted for the mirrors. Light entering one of the shorter sides by total internal reflection passes out the other short side.

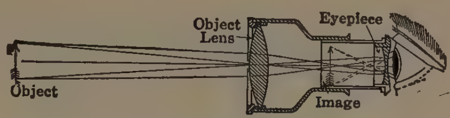


Fig. 279. — Opera glass.

Field glasses. Field glasses and opera glasses are made on the same principle as Galileo's telescope, which he constructed in 1610, and with which he could magnify 30 diameters. Galileo's telescope differs from our present telescopes only in the eyepiece. Galileo used a double-concave lens instead of a double-convex lens. The concave lens is placed between the objective and its principal focus. This causes the rays to diverge, so that as they enter the eye they make a larger visual angle, and so magnify the object. The ordinary opera glass has a double concave eyepiece and magnifies from three to four times. High-power field glasses of this type are awkward to carry because of the long barrel necessary.

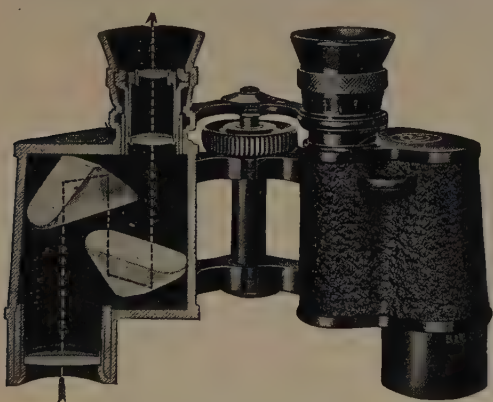


Fig. 280. — Prismatic construction and path of light rays in the binocular.

The stereoscope. Since our eyes are several inches apart, each eye sees a slightly different picture. A landscape looks flat when seen through one eye alone; but when it is seen with both eyes, relative distances are more apparent and the view has what we call *depth*. An ordinary photograph taken with a one-lens camera is flat, even though seen with both eyes. To remedy this fault, a camera with two lenses, separated by a distance equal to that between the two eyes, is used to take two pictures simultaneously.

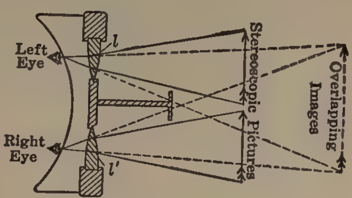


Fig. 281. — The stereoscope.

These two pictures are mounted beside each other and viewed through the stereoscope. Both pictures are seen at once, each through a prism lens so arranged that the two images coincide. Since each eye sees the

FIG. 282. — Field of the binocular (above) and field of the ordinary glass (below).

same image that it would if observing the real object, the sense of depth or distance is very apparent. Objects in the picture are slightly magnified and stand out clearly in relief. Binocular vision seems to add a third dimension to our picture.

Prism binocular. This compact field glass, having the power of an ordinary field glass or telescope of nearly three times its length, is made possible by the use of two right-angle prisms. The lenses are the same as in the telescope. The image is brought right side up through the reflection in one prism, and corrected for reversal of right and left by the second prism, so that as seen the image is perfectly natural.

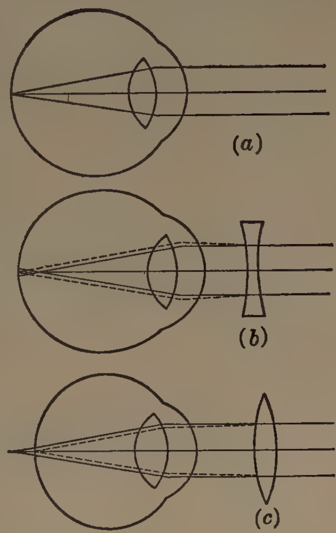


FIG. 283. — Differences in normal eye (*a*); the near-sighted eye (*b*); and the far-sighted eye (*c*). The dotted lines show the path of the rays after the correction by glasses.

Lenses for eye defects. Tests show that there are very few normal eyes. Some people see near-by objects most clearly and are therefore said to be **near-sighted.** Others see distant objects most clearly and are said to be **far-sighted.** A clear distinct object can be seen only when the image is focused on the retina. Focus adjustment for distant bodies consists in relaxing the muscles and allowing the lens of the eye to flatten or become thin; *for near bodies, the lens must be thickened to produce the proper focus.* When the normal eye is relaxed, parallel rays of light focus on the retina. When a person is near-sighted, these parallel rays *focus in front* of the retina. This defect results from inability to make the eye lens thinner. A concave lens in front of the eye corrects the defect, since it reduces the convergence of the rays and thus makes them focus farther back. When a person is far-sighted, the parallel rays *focus behind* the retina. This defect results from inability to thicken the lens sufficiently to bring the focus forward to the retina. A convex lens in front of the eye gives the effect of a thickened eye lens and thus corrects far-sightedness.

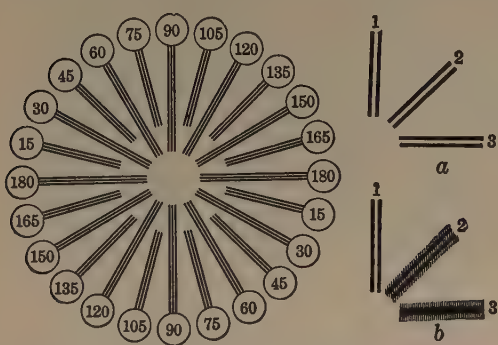


FIG. 284. — Wallace's chart for determining astigmatism (reduced). (*a*) Appearance of lines to normal eye. (*b*) Appearance of lines to astigmatic eye.

Near-sightedness, called **myopia,** occurs when the eyeball is so elongated that the lens is too far from the retina; far-sightedness, called **hypermetropia,** occurs when the eyeball is too short from front to back. The cornea of the eye is often flatter in far-sighted than in normal eyes.

If the curvature of the cornea or of the lens is uneven, all the rays which enter the eye will not focus at the same place. This makes it impossible to see all parts of an object clearly at the same time. While some parts will be seen distinctly, other parts will appear blurred. This defect is known as **astigmatism.** A lens for the correction of astigmatism must be prepared for each individual eye. Where there is a flat place on the cornea there must be a convex place on the lens, and where the cornea bulges out the lens must be made concave.

Power of eyeglass lenses. The power of a lens is measured in *diopters* by the oculist. One diopter equals 100 centimeters, divided by the focal length of the lens in centimeters.

A lens with focal lens of 400 cm. is ¼ diopter.
A lens with focal lens of 200 cm. is ½ diopter.
A lens with focal lens of 100 cm. is 1 diopter.
A lens with focal lens of 50 cm. is 2 diopters.
A lens with focal lens of 25 cm. is 4 diopters.

The oculist can measure the focal length of the eye lens, and then calculate the correct focal length of an eyeglass to give the proper combination for good vision. The oculist's prescription will properly make

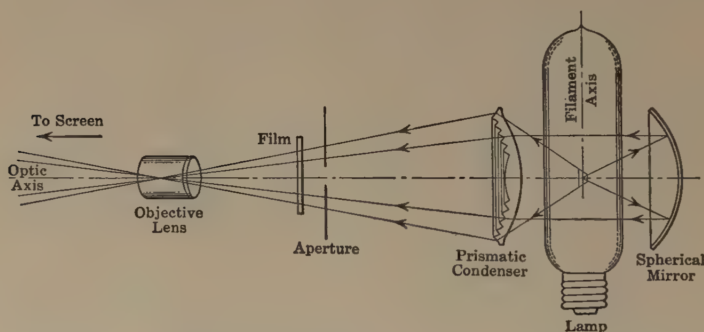


FIG. 285. — Arrangement of essential parts of a projection lantern.

use either of the plus (+), or the minus (—) sign. Plus means a convex and minus a concave lens. Near-sighted eyes are provided with negative diopter lenses; the far-sighted eyes require positive diopter lenses.

Eyeglasses. In ordinary eyeglasses, the edge of the glass is farther from the eye than the middle; consequently, when one turns the eye to

see objects through different parts of the glass, a change in focus of the eye must be made. By means of a concave-convex lens, known as the **toric lens,** the eye is more nearly equidistant from all parts of the glass. This not only reduces the amount of refocusing, but also increases the field of vision.

As a rule, elderly people need two pairs of glasses, one for seeing near objects, the other for seeing distant ones. Since near-by work is seen by looking downward, and in distant vision the eyes are raised, it is possible to combine the two sets in one pair of glasses. These are the **bifocal glasses.**

For any eye defect the lens must be fitted to the eye which is to use it; *only those who have specialized in the work should be trusted to prescribe for one's eyes.* A skilled oculist can tell the trouble and prescribe the remedy; the optician can prepare glass lenses according to the oculist's prescription. Many eye defects, if attended to while one is young, may be kept from growing worse, and some of them may be cured. Neglect of small eye troubles will bring serious ones later on.

The projection lantern. The stereopticon or projection lantern, by which pictures, either from lantern slides or films, are thrown on the

Fig. 286.—Light beam in picture-projecting system using a prismatic condenser.

screen, has a powerful light. If this is an incandescent lamp, a concave mirror is placed back of it. Just in front of the lamp are the **condenser lenses,** whose purpose is to pick up the angular rays of light from the lamp, covering a large area, and throw them forward in a slightly converging beam into the **projection lens.** The condensers increase enormously the amount of light which enters the projection lens, and thereby greatly increase the intensity of light on the screen. The

positions of these parts will readily be seen by consulting Fig. 286. The lantern slide, inverted, is placed just in front of the condenser lenses. By moving the projection lens forward or backward a clear picture is secured on the screen at some distance in front.

The motion-picture projector. The projection is just the same in principle as the enlarging camera, but the picture is enlarged more and is thrown on a screen to be viewed rather than on the paper for making a print. The enlarger does not have the condenser lenses. The motion-picture projector has the same parts as the projector of still pictures, but in addition it has a motor to run the film along through the beam

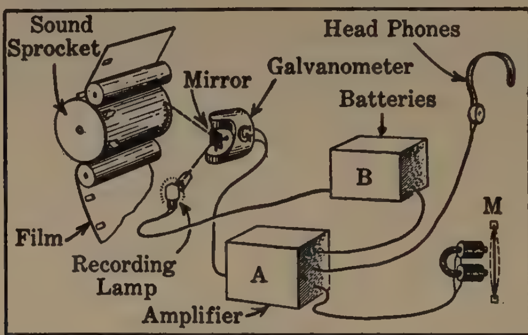


FIG. 287. — How the sound record is made upon the film. *M* is the diaphragm of the microphone.

of light. The film has a series of pictures taken of a moving object at the rate of about 16 per second. These pictures are thrown upon the screen at this same rate. The film is actually still while the light is passing through it. A shutter cuts off the light while the film is moved forward to the next picture. When pictures are shown as fast as 16 per second, because of the persistence of vision one picture is not lost in the eye before the next one appears, and so the pictures blend together and produce the illusion of motion.

Film sound records. In " talking pictures " a sound record is made upon a film. It is usually on the edge of the same film that carries the picture. The energy changes involved in producing the record are these: Sound vibrations in the microphone produce a pulsating electric current of varying intensities which operate a mirror galvanometer. The mirror oscillates weakly or strongly according to the pulsating current. The mirror reflects a tiny beam of light from the recording lamp to the film track along the edge of the film. When the mirror is still, a uniform band is the result, but as modulation occurs the oscillating mirror causes the beam of light to make a wavy line or a series

of peaks and valleys in the sound track. After the film has been processed and the record made permanent, it is ready for projection.

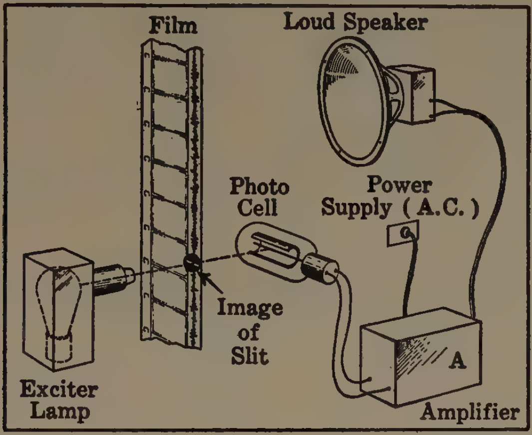


FIG. 288.—How the sound track through the help of light and electricity reproduces the original sound.

In order to produce sound from this film, a beam of light is directed through the sound track of the film into a photoelectric cell, where variations in the electric current are produced corresponding to the variations in the sound track on the film. These variable currents are amplified and sent out, to the loud speaker where the resulting vibrations produce the original sounds which were recorded on the film.

SUMMARY

1. The reading glass and the simple microscope consist of a double-convex lens. When an object, placed under the lens within its focal length, is viewed through the lens, it appears much enlarged.

2. The compound microscope has a lens to magnify the enlarged image of a second lens, the objective.

3. The refracting telescope is the same in principle as the compound microscope, but the objective has a longer focal length than the microscope. The image is seen inverted, but the introduction of a third lens makes it erect.

4. The reflecting telescope collects light in a large concave mirror. This produces a bright real image that can be observed through the eyepiece.

5. Both kinds of telescopes are used more for photographing the heavenly bodies than for direct observation.

6. Field glasses and opera glasses are in principle like the telescope,

but are arranged for the use of both eyes. By using right-angle prisms for reflecting light, the length of the field glass is greatly reduced.

7. The stereoscope is a device for making pictures show depth, as if the original were seen directly. This is accomplished by taking two photographs, one representing the object as seen by the right eye and the other as seen by the left, and then viewing these two, one with each eye, through a magnifying glass of low power.

8. The periscope utilizes double reflection by two parallel mirrors having a 45° angle to the line of sight, in order to enable an observer to see over or around obstructions.

9. Far-sight is a defect which causes distant objects to be seen more clearly than near ones. The far-sighted eyeball is too short, and the lens cannot be thickened sufficiently to bring the image of a near object forward to the retina. The remedy is a convex lens placed in front of the eye.

10. Near-sight is a defect which makes it impossible to see objects clearly unless they are near the eye. The near-sighted eyeball is too long, and the lens cannot be made thin enough to bring the focus of a distant object back to the retina. The remedy is to place a concave lens in front of the eye.

11. Astigmatism is the most common eye defect. It can be remedied by corrections applied to a lens to correspond to the defects in the eye cornea or lens.

12. Toric lenses give a larger field of vision than common lenses. Bifocal glasses combine near- and far-sight lenses in one pair of glasses.

13. In still and motion-picture projectors, lenses concentrate a strong beam of light upon the curtain. These lenses must be of the right focal length to give a clear image of the picture which is on the slide or film.

14. In making a sound film, a beam of light is directed towards the film through a film gate. The gate is controlled by an electric current which varies according to the sound waves in front of the microphone. The bands of varying densities on the film will allow varying intensities of light to act upon a photoelectric cell and produce fluctuating electric currents which after being amplified produce sound.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Through the telescope.
2. Through the microscope.
3. The periscope — the eye of the submarine.
4. Measure the magnifying power of a small telescope or field glass.
5. Motion-picture projection.
6. The 200-inch reflecting telescope.

CHAPTER XXI

THE CAMERA AND PHOTOGRAPHY

Amateur photography is a pastime that has come to be almost a universal activity or hobby of some member of the family. It makes possible the keeping of records of the development of the youthful members of the family, of the family pets, and of the various excursion and vacation trips. The cost of a camera may be from nothing — with

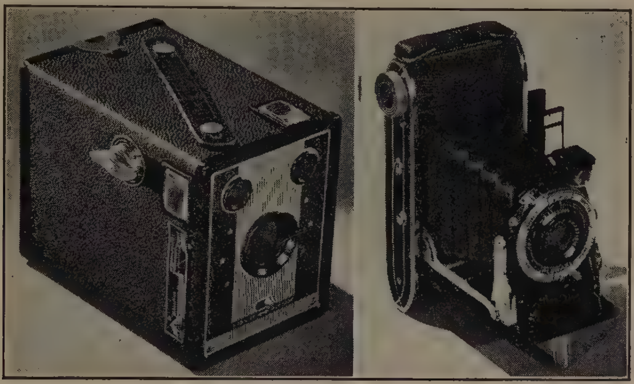


FIG. 289. — Agfa Shur-Shot box camera and Agfa Plenax folding camera.

a homemade pinhole camera — to several hundred dollars for a camera with a series of high-grade lenses.

The camera. The camera is much like the human eye, but whereas the retina of the eye can hold its image but a fraction of a second, the film or plate of the camera can be so treated that the picture will be permanently preserved. The analogy between the camera and the eye is striking. The camera is a light-tight box, having a shutter in front of the lens, through which light may be admitted or excluded at will. There is a diaphragm which regulates the size of the opening through which light enters the camera. In the front of the camera there is a lens, and when the operator is ready to take a picture, a sensitive plate or film is placed in the back. The film corresponds to the retina of the eye.

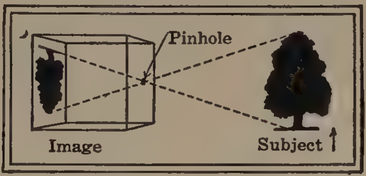


FIG. 290. — Light from an object passing through a pinhole into a closed box produces an inverted image of the object.

There are two types of cameras: non-focusing, or fixed focus, as the ordinary box camera, and the focusing camera, having a bellows or equivalent device for changing the distance between the film and the lens.

The diaphragm and "stops." The size of the opening by which light may pass through the lens is determined by the *diaphragm*. By mechanical means a variety of openings of different sizes may be secured. The various openings are termed *stops*. The small stop allows only the center of the lens to be used. This is the best part of the lens and gives a clear, distinct image. As the size of the stop is increased, more of the outer edge of the lens is used. Only expensive lenses will give a sharp image at the largest stop. There are two systems of stops. In the Uniform System (U.S.), each higher number has half the area of the one before and therefore requires twice the

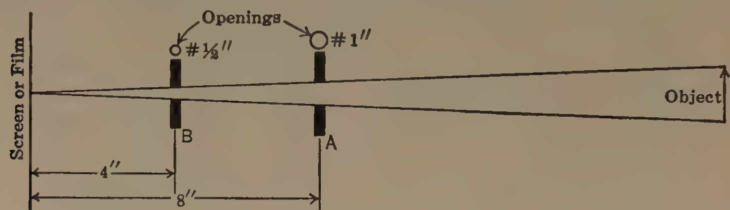


FIG. 291.—The exposure value of a lens is the ratio of its focal length to its largest usable stop.

length of exposure. Stop 8 is a large opening and stop 32 is small. In the Uniform System if 1 second is the correct exposure at stop 8, 2 seconds will be required at stop 16, and 4 seconds at stop 32. Since the small opening gives sharpest detail, it is used when photographing a drawing or copying another photograph. The *f* system is defined as the ratio of the diameter of the opening to the focal length of the lens. In stop *f*.8 the diameter of the opening is $\frac{1}{8}$ the focal length. In the *f* system *f*.16 has $\frac{1}{4}$ the opening of the *f*.8 and therefore requires four times as long an exposure.

All stops having the same relative size have the same exposure value. By relative size is meant the ratio of focal length to the stop or diaphragm opening. A lens with focal length 8 inches used at 1-inch opening has the same exposure value as a lens with focal length 4 inches used at $\frac{1}{2}$-inch opening. The diagram helps to see that just as much light falls on the screen (same confining angle) through a $\frac{1}{2}$-inch opening at *B* as through a 1-inch opening at *A*. All the light that would come through the 1-inch aperture at *A* will come through the $\frac{1}{2}$-inch aperture at *B*, which is only half as far from the film. The speed of a lens is indicated by the largest exposure value at which it can be used.

The lens with focal length 8 inches usable with 1-inch opening would be an *f*.8 lens. The lens with focal length 4 inches usable with ½-inch opening would also be an *f*.8 lens. The 4-inch focal-length lens usable with 1-inch opening would be an *f*.4 lens. Any lens can, of course, be used at any smaller opening than that designated as its *f* value. The large stops give some parts of the picture in sharper focus than others. For sharpest detail of all the picture the smaller stops must be used. Remember, however, the smaller the stop the longer the exposure.

Camera lenses. A single lens is found in the cheapest cameras. The violet rays (actinic rays) are the ones that are most active in making our pictures, but most of the visual rays by which we see objects come from the green, yellow, or red rays. A single lens, used wide open, focuses the actinic rays at *A*, Fig. 292, but the visual rays by which we focus the picture are focused farther away, at *B*. Since flint glass bends the actinic rays more than crown glass does, it is possible to combine a negative flint lens with a positive crown lens so that the actinic or chemical rays and the visual rays are focused at the same point, or at *C*. Such a lens gives no separation of colors and is called an **achromatic lens.**

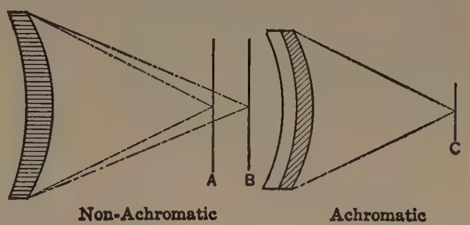


Fig. 292. — Single meniscus lens at left and double combination lens at right.

Only three sizes of stops are used with single lenses: the largest for ordinary snapshots; the medium for snapshots of views on the water, or for time exposures; and the smallest for time exposures only.

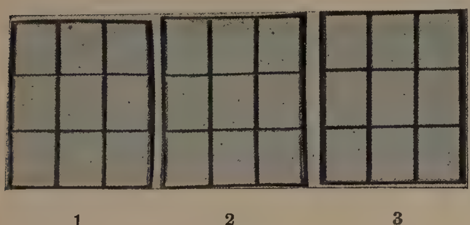


Fig. 293. — Parallel lines distorted by meniscus lens (1 and 2). Stop back of lens (1). Stop in front of lens (2). The rectilinear lens gives no distortion (3).

The single lens tends to distort straight lines, particularly the marginal lines of the picture; this is sometimes seen in the vertical lines in the photographs of buildings. It is not so apparent in small pictures as in large ones. This distortion is corrected by using a double combination lens, the parts being separated by the diaphragm. This is the **rapid rectilinear lens** shown in Fig. 294. The largest opening that can be used with the rapid rectilinear lens is stop 8.

Lenses that are more highly corrected than the rapid rectilinear lenses, so that they may be used at larger apertures than stop 8, are called **anastigmats.** A rapid rectilinear lens can be used with an opening with a diameter up to $\frac{1}{8}$ its focal length, but an anastigmat will give sharp pictures with an opening much larger than that. An *f*.6.3 lens (diameter of opening approximately $\frac{1}{6}$ its focal length) admits over 60 per cent more light. Anastigmatic lenses have two advantages: they make possible taking pictures under such poor lighting conditions that cheaper lenses would fail; they permit photographing objects moving at high speed without showing blur. With these as with any lens the increase in size of the opening is attended by some loss of depth of focus. Objects at a certain distance may be in sharp focus, but those objects nearer or farther away will be less sharp. Most fast movements can be caught without a blur with anastigmats at these exposures: *f*.4.5 in $\frac{1}{200}$ second; *f*.5.6 in $\frac{1}{150}$ second; *f*.6.3 in $\frac{1}{100}$ second. Many camera lenses and shutters are now used at $\frac{1}{300}$, $\frac{1}{500}$, and $\frac{1}{1000}$ second.

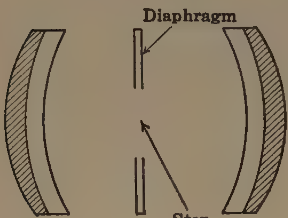


Fig. 294. — Double combination of lenses used in rapid rectilinear lens.

The focus. In Fig. 295, *A* is the focus for objects 10 feet from the lens, and *B* the focus for objects 100 feet from the lens. If the focal length of the lens is 3 inches, the distance between *A* and *B* is $\frac{3}{16}$ inch, but if the focal length is 12 inches it is $1\frac{3}{4}$ inches from *A* to *B*. If a camera has a lens with 3-inch focal length and the plate is placed halfway between the two focal points *A* and *B*, no matter at what distance the object is, it will be very little out of focus. Such a lens is used in **fixed-focus cameras** to take pictures up to $3\frac{1}{4}$ by $4\frac{1}{4}$ inches. With the size of stop used in these cameras, no blurring due to poor focus can be detected, and the camera has the advantage of being always in focus. With a focusing camera the size of stop used is important. If you have focused upon an object 15 feet away with a large stop, objects 10 feet and 20 feet away will be somewhat blurred; but as you reduce the opening, they become sharper, and at stop 32 all objects 10 feet away

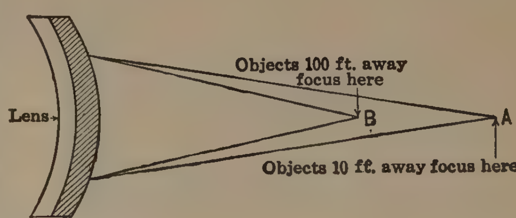


Fig. 295. — Position of image depends upon distance of objects.

and beyond will be clear and distinct. For artistic effect, an object in the foreground may be in sharp focus while the background is indistinct. This result is obtained by using a large opening and focusing upon the near-by object.

The finder. The camera finder, like the camera, has a lens and a screen which receives the image. In one form, the mirror placed at an angle of 45° reflects the light rays from a horizontal to a vertical direction, and fixes the image on a horizontal ground-glass surface. In another type, the "brilliant," the image is focused on a screen within the finder, where it is viewed by looking through a lens. Both finders show just how much of the view will appear in the picture.

Fig. 296. — Image in the finder. Well placed for horizontal picture.

Exposures. Almost all box cameras have a stop opening of about *f*.14 and a shutter speed of $\frac{1}{25}$ second. With regular film emulsions, pictures must be taken in good light — sunshine — and not within $2\frac{1}{2}$ hours of sunrise or sunset. New fast films now available will give more latitude of exposure than that suggested above.

Focusing cameras generally have a variety of available stops and speeds. Because of the increased burden of manipulation, the beginner frequently takes better pictures with a simple cheap camera than with the expensive complicated one. The focusing, the diaphragm, and the shutter speed have to be decided upon and set before snapping the picture. Near-by objects with little or no sky, groups of people, street scenes, portraits in open shade require much more exposure than snow and marine scenes or landscapes with sky. This greater exposure can be obtained either by slower shutter action or larger stop opening. Anything that may give the slightest motion should not have longer than $\frac{1}{25}$ second shutter exposure. But the diaphragm can be opened wider for greater action of the light. The sizes of the stops are the inverse of the numbers designating them. For example, stop 8 is

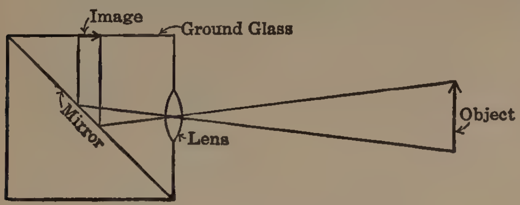


Fig. 297. — The camera finder.

larger than 16 but smaller than 5.6. When the light is poor and there is no danger of motion a time exposure is the proper thing. Experience with a given film is the best way to learn the proper exposures unless you make a rather deep study of the subject and use an exposure meter.

FIG. 298. — The exposure meter.

The exposure meter. Of the many types of exposure meters, one of the best is based on the action of the photoelectric cell. The photoelectric cell is a device by which light energy is transformed into electrical energy. Light sets electrons free when it strikes a surface coated with certain chemicals, such as potassium, cesium, and selenium. The number of electrons released varies with the intensity of light received. The photoelectric cell is so constructed that electrons set free are directed through a microammeter whose pointer moves over a scale. From the scale reading one can tell what stop and shutter speed are proper for the

TABLE XXIV

EXPOSURES FOR DIFFERENT CONDITIONS

Shutter speed for each diaphragm opening is given in fractions of a second.

	f. 4.5	*f.* 5.6	*f.* 6.3	*f.* 8	*f.* 11	*f.* 16	*f.* 22
Intense sunshine	600th	400th	300th	200th	100th	50th	25th
Bright sunshine	300th	200th	150th	100th	50th	25th	10th
Cloudy-bright	150th	100th	60th	50th	25th	10th	5th
Dull-cloudy	60th	50th	30th	25th	10th	5th	½
Very dull	30th	25th	15th	10th	5th	½	1

particular film used. If you have no exposure meter, you may expect fairly good results by following suggestions given in the exposure table. The exposures suggested are for Verichrome and Plenachrome films. For standard film, double the time; for supersensitive film, halve it.

Lighting conditions. When taking outdoor pictures it is generally best to have the sun at your back shining towards the subject. If the sun is shining toward the camera lens, the shaded side of the subject is toward the camera, and you must make allowance for the small

Fig. 299. — A silhouette.

amount of reflected light. Early morning and late afternoon sunshine is always much weaker than that at midday. Also, bear in mind that winter sunshine is much weaker than summer sunshine.

In making silhouettes, an object is purposely photographed from the dark side toward a bright light. Have the person or object so placed that the sky can be the background. In the home a person may stand or sit directly in front of a window or open door where the camera view is towards the sky. At night a sheet may be hung over an open doorway. A person sits near the sheet on the same side with the camera. A bright light shines upon the sheet from behind it. The camera is focused upon the person, and a few seconds' exposure is given.

Filters. This is the theory of the use of filters. This violet and blue colors are far more active chemically on the commonly used photographic film than the green, yellow, orange, and red. These latter colors are brightest to the eye. A scene that has much sky or reflected sky, water surface, or clouds is likely to have those parts rich in blue, violet, and ultraviolet rays much overexposed before the green to red colors have had time to produce enough chemical action to be registered at all.

It is in order to equalize the proper exposures that filters are used to reduce those rays near the violet end of the spectrum and so give the green, yellow, orange, and red a chance to be recorded on the film.

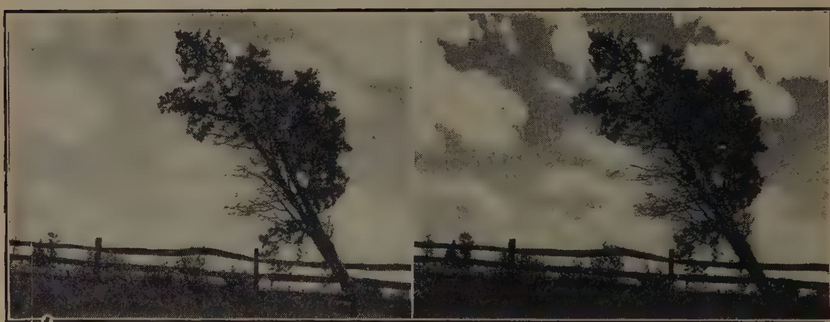


FIG. 300.—For cloud effect use a filter. Picture at right with filter.

There are green, yellow, orange, red, and haze filters. Each filter covers a particular part of the spectrum. Since they absorb certain light rays the exposure time must be lengthened. The selection of proper filters for specific purposes is too long a story to discuss here. Consult your photographic dealer for help in this.

Miniature cameras. The miniature camera is popular not only for its small size and weight but also because of the large number of shots at one loading and small cost of the negatives. To this we should add that the perfection of a film of very fine grain makes it possible to enlarge the pictures to almost any desired size without showing the grain. The cost of an up-to-date fully equipped miniature camera, with built-in range finder, telescopic sight, quick focusing, and a set of accessory lenses for portraits, telephoto work, color work, and filters may run into hundreds of dollars. But there are fairly good miniature cameras for less than $15. With the new extra-rapid film the amateur does not need the really expensive lenses. The film used is 35 mm., and one roll will take 36 pictures 1 by 1⅜ inches.

Making the negative. The exposed film looks no different from the unexposed film. It must be developed to bring out the picture. The developer is a chemical solution that will act upon the silver salts and deposit silver upon the film wherever light has acted upon it. Those parts which received strong light will get large deposits of silver; those which received weak light

Photographed by Agfa Ansco Corporation.

FIG. 302. — *A.* Under developed negative. *B.* Properly developed. *C.* Over developed.

FIG. 301. — Positive of the negative at the left.

will get small deposits; and where no light reached the film there will be no deposit of silver. This developing process must be carried on in the dark, though with some films a feeble red light may be used. The film is run through a tray or suspended in a tank of developer for a definite length of time, depending upon temperature and strength of the developer. After removal from the developer and rinsing in water,

the film must run through or remain in a fixing bath for 10 to 20 minutes before it is brought out into the light. The fixing bath — a solution of

Photographed by Agfa Ansco Corporation.

Fig. 303. — Effect of varying time of exposure in printing. Under exposed. Properly exposed. Over exposed.

Photographed by Agfa Ansco Corporation.

Fig. 304. — Results with different grades of paper on same negative. Soft print. Normal print. Hard print.

sodium hyposulfite — dissolves the silver salt not acted upon by the light during the exposure in taking the picture. After removal of the silver salt the film is no longer sensitive to light; it is washed about 20

minutes in running water and hung to dry. The film is now a series of negatives with light and dark gradations just the reverse of what they were in the original subjects photographed.

Printing. There are two printing processes. In **contact printing,** paper and negative are in contact. Light comes through the negative and acts upon the silver salts in the paper in proportion to the density of the silver deposits in the negative. In **projection printing,** paper and negative are separated and the picture is focused upon the paper at a distance from it. This is the method in making enlargements, and it may be used for smaller pictures. In both methods the coated side of the paper is towards the coated side of the film. After the exposure

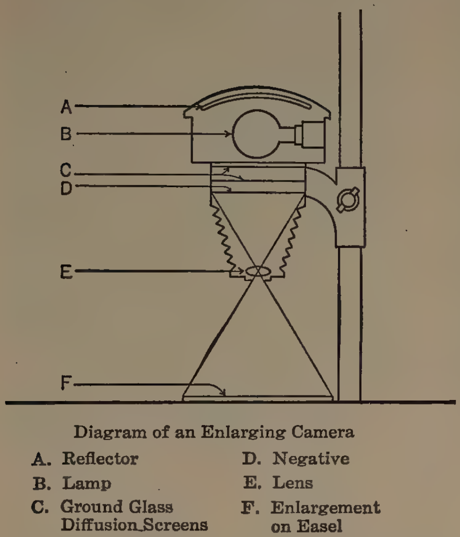


FIG. 305.—Projection printer or enlarger.

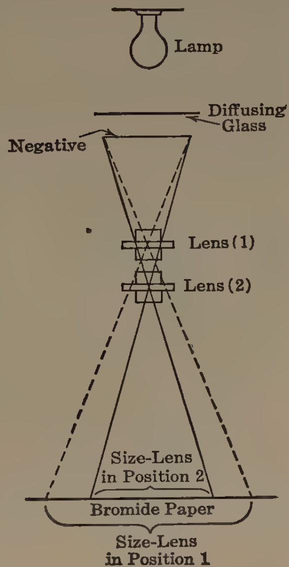


FIG. 306.—Showing how moving the enlarger lens changes the size of the picture projected.

the paper must be developed and fixed in much the same manner as the negative. Since the print has the light and dark areas reversed it is called a positive.

Enlargements. Many photographs taken by amateurs will make beautiful enlargements. Practically all pictures taken with the candid or miniature camera must be enlarged to make a satisfactory album print. The process is not too difficult for the amateur. It is made by sending light through the negative placed between the principal focus (F) and twice the focal length ($2F$) of the lens. This will produce a

real, inverted, and enlarged image beyond $2F$ on the other side of the lens. (Review the diagram in Fig. 236.) Since the enlarger really projects a picture by the same principle that pictures are projected upon a screen in a darkened room, this method is also called projection printing. The size of the enlargement depends upon the relative positions of the negative and the lens. As shown in the diagram by the dotted lines, if the lens is moved nearer to the negative the image will be larger. The print is made on bromide (enlarging) paper which is more rapid than the regular paper used in making contact prints.

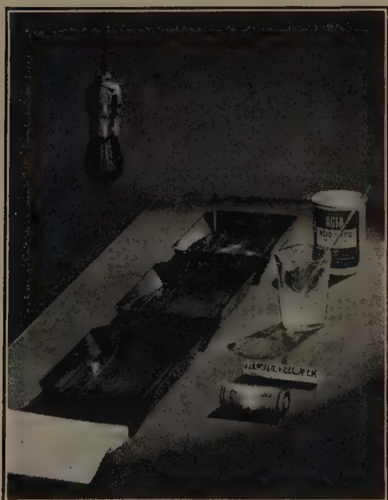
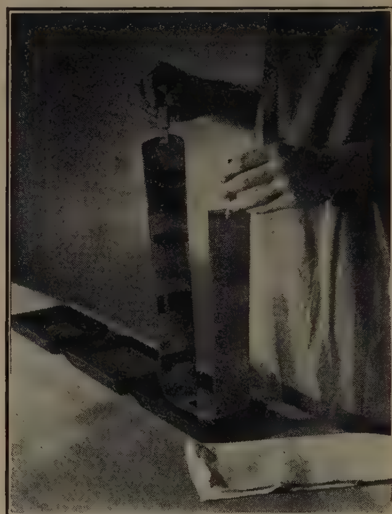


Fig. 307. — Dark-room equipment.



Photographed by Agfa Ansco Corporation.

Fig. 308. — Developing a roll film.

A home outfit. Much of the pleasure of amateur photography comes after the pictures have been snapped, provided one has the facilities for making his own prints. The essentials for this are not too elaborate for the average boy or girl who is really interested. Find a small room which can be made absolutely dark. Preferably there should be running water, but one can prepare solutions outside and have basins of water carried in for washing. After prints or films have been fixed in the hypo bath they may be washed in a lighted room. Trays, red light, printing frame, measuring glass, together with enough printing paper, developer, and hypo to start you off can be purchased for about three dollars.

Home portraits. If you attempt home portraits in the daytime, direct light from a window may light one side of the subject and a white

cloth or paper reflector may be so placed that it will reflect enough light to the other side of the subject. The two sides should not be equally lighted, else the result will be a flat, expressionless picture. Portraits at night are possible now with the fast films and strong lights. Two

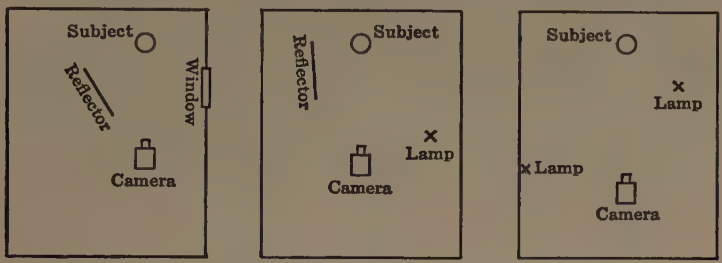


FIG. 309.—Lighting arrangement for home portraits.

bulbs are available. One is the photoflash bulb, which can be used but once. It gives an instantaneous exposure. The other is the photoflood bulb, which gives a very bright light. One of these may be used with a reflector, or two may be used, one much nearer than the other and giving light from different sides. Even ordinary light bulbs — 100 watts — will give good pictures if proper exposure is allowed. They are not so powerful as the photofloods, and so require longer exposure. The diagrams suggest possible arrangements.

Photoflood lamps. Photoflood lamps come in two sizes. Number 1 has an average life of 2 hours and is of about 750-watt capacity. Number 2 has an average life of 6 hours and is of about 1500-watt capacity. The brilliant light results from use of overvoltage for the filament. This is the cause of its short life compared to our regular lamps. If the floods are burned only as long as necessary for the picture they will not prove to be expensive.

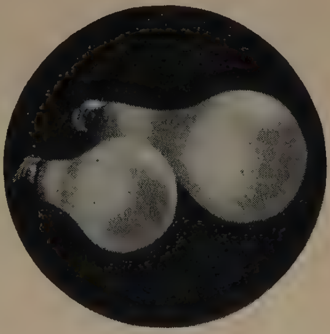


FIG. 310.—Photoflood lamps.

SUMMARY

1. The essential parts of the camera are a light-tight box, a lens with shutter, diaphragm, and a place for a plate or film at the end opposite the lens.

2. The cheapest cameras have a single lens. A better lens, which is called *achromatic,* is made by combining a flint-glass lens with a

crown-glass lens. The *rapid rectilinear lens* is the next higher quality and consists of a double combination lens whose parts are separated by the diaphragm. The *anastigmat* is an expensive lens which has been so highly corrected that it can be used at a much larger opening and so reduce the time of exposure.

3. A focusing camera is one having a lens with a relatively long focal length. The universal-focus or fixed-focus camera has a lens of so short a focal length that whether the objects to be photographed are near or far they are all in fairly good focus.

4. The fixed focus or box camera is easier to operate, but the bellows camera with a good-quality lens offers greater possibilities for picture making.

5. The camera " stop " is the opening through which light passes. It is controlled by the diaphragm. The numbers designating the stops are inversely as the sizes of the openings. For example: f.6.5 is a large opening and f.32 is a small opening.

6. The larger the stop opening, the more light enters the camera; the smaller the stop opening, the sharper detail and the greater the depth of field in which objects will be in good focus.

7. Exposure meters help one to give proper exposures.

8. Filters are useful for cloud effects and views with much sky or water.

9. When an exposed film has been developed and fixed it becomes a negative.

10. Positive prints are made the same size as the negative in contact printing and larger than the negative by projection printing.

11. Prints, like films, must be developed, fixed, and washed.

12. It costs very little for equipment; one can do his own developing and printing at home.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Pinhole photography.
2. History of photography.
3. Making silhouettes.
4. Color photography.
5. Make a printer.

CHAPTER XXII

THE HOME WATER SUPPLY

Source of water supply. Directly or indirectly, the source of our supply of water for domestic and industrial purposes is rain. In some country homes a rain barrel is still used; in many more, rain is collected from the roof but stored in a cistern. By means of suitable devices, the first roof wash can be automatically discarded and the clean water collected and stored. If this stored water is safeguarded against pollution, it makes a satisfactory home supply. It is soft water and so does not waste soap.

The rain water that remains on the ground or later comes to the surface in lakes and rivers is a source of water supply for our larger towns and cities. The main supply for the country home is that rain water which has soaked into the earth and is later taken from springs and wells.

Wells. Water sinks quickly in a porous soil, such as sand; but compact soils, for example, a very clayey soil, resist the movement of water. A layer of clay, like a layer of rock, is practically impervious to water. When water soaks into the ground, it will at some depth encounter an impervious layer, and for some distance above this the soil will become saturated with water. The surface of this water, known as *ground water,* is called the **water table.** In some places the water table will reach the surface and a body of surface water may be found there. In other places the water table may be a few feet below the surface, while in still others you might dig a hundred feet and not encounter water. The water table, as might be expected, varies with the season of the year, moving upward during times of plentiful rainfall and sinking during a drouth. A **well** is a hole dug into the earth to a depth below the water table. The water table marks the level to which the well will be filled with water.

Artesian wells. Alternate layers of porous and compact soil are of frequent occurrence. Owing to geological changes in the earth's crust, these layers have been folded, in many places, so that one of the given series of layers will be, perhaps, thousands of feet higher than another, distant part of the same layers. Erosion may have left the high part exposed, and here rain will enter the porous layer. In time the water, confined in this porous layer by the impervious layers above and below,

will rise within its limited space until it stands at a level which is higher than the surface of the land at some distant point. If then this layer is tapped by boring a hole into it at its lower level, the pressure of water standing at the high level, even though this be miles away, will cause the water to gush forth in a constant flowing stream. Some artesian wells are more than a mile in depth.

Springs. Sometimes a break in the upper impervious layer allows water from the porous layer below to escape. When this reaches the surface of the ground, it makes a *spring*. Springs more commonly result when the water table reaches the surface on a hillside. Many hillside springs cease flowing in dry weather because of the falling of the water table. Spring water and well water have certain soluble materials taken from the soil, and in a given locality are usually of the same general character.

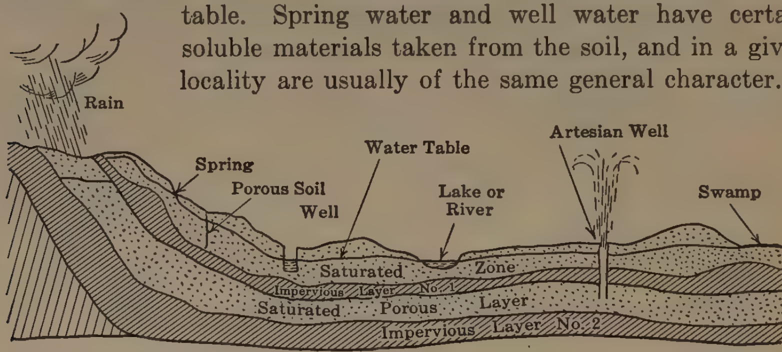


Fig. 311. — Rainwater stored in the soil supplies springs and wells with water.

How the country house is supplied with water. When a house is located under a near-by hill, sometimes a spring or well can be located above the home, so that water will flow, by force of gravity, through a pipe to the house. The method takes advantage of the well-known principles that " water runs downhill " and that " water seeks its own level." Water will rise in pipes to the top floor of the house, if this is not higher than the source. Besides the old-time bucket and windlass, many types of pumps are available for raising water from a well which is lower than the house.

The lift pump. The most common pump is known as the **lift** or **suction pump.** Its operation depends upon the pressure of the atmosphere. A pipe extends from the cylinder of the pump into the water in the well, Fig. 312. At the top of the pipe, where it joins the cylinder, there is a valve, *B*, opening upward. Inside the cylinder is a tight-fitting piston with a valve, *A*, also opening upward. On the *down stroke* of the piston, the air between the two valves is compressed and opens valve *A* to escape. On the *up stroke* of the piston the overlying air holds valve *A* tightly closed. The rising piston increases the space

below it, and so decreases the pressure upon the valve B and also upon the water inside the pipe extending below the valve. The pressure of the atmosphere on the surface of the water in the well, W, pushes water into the pump to equalize the pressure. On the next down stroke of the piston the lower valve closes and the upper valve opens, allowing air or water to pass through it. After a few strokes, the cylinder is filled with water and the water is lifted until it runs out of the spout.

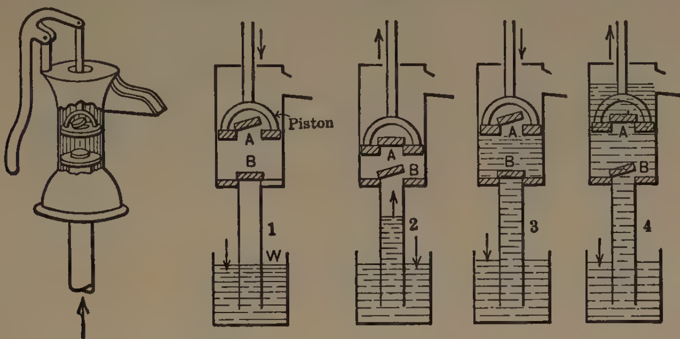


FIG. 312.—Action of the lift pump.

Since the atmosphere cannot lift a column of water more than 34 feet high, piston and valve A must not rise more than 34 feet above the water surface; in practice, 25 to 27 feet is about the limit, instead of 34 feet. This is due to leakage around the valves, to dissolved air which escapes from the water when the pressure is removed, and to the fact that water vaporizes in increasing amounts as the pressure is reduced. When the valves have become dry, it is frequently necessary to add a little water to the pump to start the action. This is known as *priming*.

The spray pump. A type of force pump described in the next paragraph may be used to produce a stream of liquid under high pressure. With a suitable nozzle this stream may be broken into a fine, mistlike spray. Another type of spray pump depends upon the principle of the atomizer. When a strong current of air is blown from a jet tube, it reduces the pressure immediately surrounding the current of air near the end of the tube. If the narrowed mouth of a second tube is close to the air jet and its lower end is immersed in a liquid, atmospheric pressure will force the liquid through the tube, provided the tube is short. When the liquid meets the jet of air it is scattered in fine spray.

FIG. 313.—Sprayer; atomizer principle.

The force pump. A common type of force pump is shown in Fig. 314. A solid piston is moved up and down in the cylinder of the pump. An outlet pipe, containing a valve, *A*, connects with the cylinder near the bottom. This leads to an air dome from which compressed air forces the water out through the delivery pipe. When the piston is raised, the pressure below it is reduced. Back pressure from the delivery pipe keeps the valves in the outlet pipe closed. Atmospheric pressure forces water up into the cylinder of the pump, opening the valve *B*. On the down stroke the lower valve, *B*, is closed and the water is pushed out through the outlet valve, *A*. A part of the water compresses the air in the air dome and a part goes directly out through the delivery pipe. During the next up stroke, the compressed air in the air dome forces water out, so that a continuous flow from the delivery pipe results. Force pumps are used for lifting water to high levels, for delivering water under high pressure, and for spraying purposes.

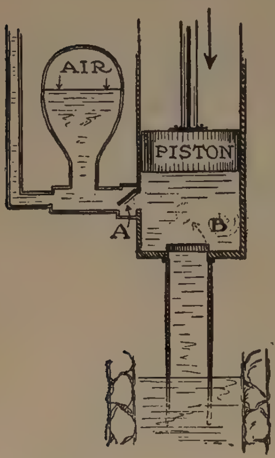


FIG. 314. — The force pump.

Hydraulic ram. A hydraulic ram is an automatic pump which raises water to a higher level than its source. It can be used only where there is an abundance of water, for it works on the principle

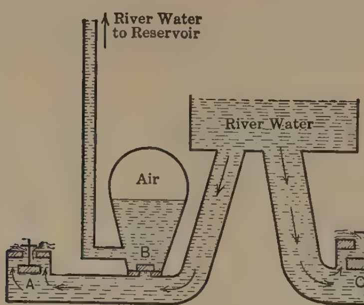


FIG. 315. — Hydraulic ram.

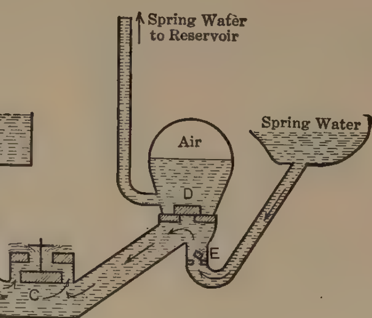


FIG. 316. — Another type of hydraulic ram.

that a large amount of water falling a short distance can raise a small amount of water a greater distance. When water flowing in large volume from the source, through the overflow valve *A*, Fig. 315, reaches a sufficient speed, it lifts and closes the valve. The momentum of this

running water is so great that a portion of it is forced through the delivery valve *B*, into the air chamber. Here it compresses the air and eventually passes on through the delivery pipe to the storage tank, from which it may be distributed by gravity.

By means of a ram of slightly different construction, river or lake water may serve as the source of power to drive pure spring water into the storage tank. A study of Fig. 316 will show how this ram works. When valve *C* is open, spring water and river water both run out. The space in the vicinity of valve *D* is entirely filled with spring water; when *C* closes, the back pressure closes valve *E* and forces spring water through valve *D*.

Pressure tank. Where there is no city water supply, the convenience of such distribution may be secured by means of the *pressure tank*. This is a large, air-tight steel tank usually located in the cellar. There are two pipe connections near the bottom of the tank, one being the inlet and the other the outlet. The force pump, driven by hand or by power, forces water from its source into the tank. At the start the tank is full of air. Changes in volume of the air follow from an application of Boyle's law, namely: *that at constant temperature, the volume of a gas varies inversely as the pressure*. As water enters, the air is compressed into smaller space, its pressure increasing all the time. If water fills the tank half full, the pressure of the confined air is doubled; that is, its pressure is equal to 2 atmospheres. When water flows out of faucets it must overcome a pressure of 1 atmosphere. This would leave a pressure of 1 atmosphere available to lift water in the pipes to the floor above. Since the *pressure of a gas varies inversely as its volume*, when the tank is three-fourths full of water and the air occupies but one-fourth its original volume, the air would be under a pressure of 4 atmospheres. This would give a force of 3 atmospheres available for lifting water. If we recall that 1 atmosphere is able to sustain a column of water about 34 feet high, it will be seen that a tank three-fourths full of water has sufficient pressure to deliver water from a faucet 100 feet high. If faucets were placed at the same level as the tank, water would be delivered at a pressure of nearly 45 pounds per square inch. A glance at the pressure gauge on the delivery pipe will indicate whether or not it is necessary to pump more water in. Automatic devices may be installed to keep the water at the desired pressure without any personal attention.

Sometimes air is pumped by an air pump into the top part of the tank to increase the pressure and make it possible to lift the water to greater heights. Every pound of pressure is able to raise water 2.3 feet. The pneumatic tank has several advantages over an elevated

tank which distributes water by gravity. It is placed in the cellar or may even be buried in the earth, and is thus protected from severe warmth of summer and freezing in winter. It is impossible for dust and germs to reach it. A pressure of 60 pounds is equivalent to having a water tank elevated to a height of 101 feet. Water in the elevated tank has 1 atmosphere of pressure on its surface. This balances the back pressure of the atmosphere at the faucet.

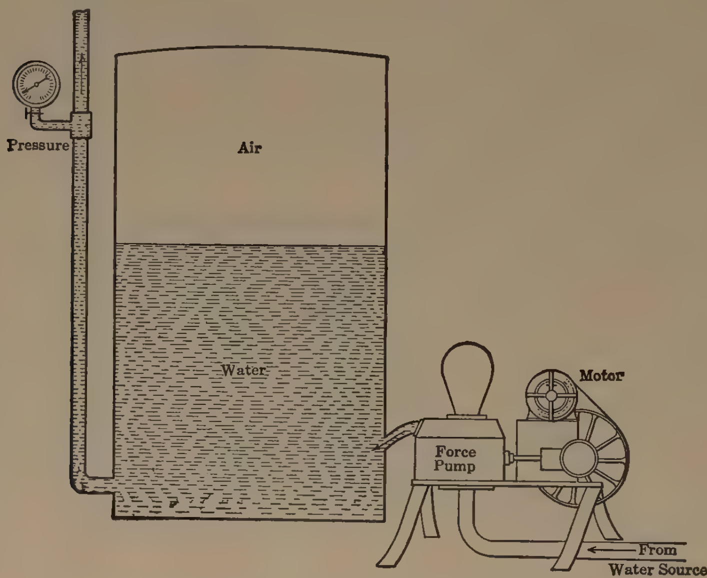


Fig. 317. — The pneumatic tank.

City water supply. Small cities and towns sometimes obtain enough water to supply their needs from springs or wells, but usually it is necessary to go to rivers or lakes for such supply. In exceptional cases a lake may also serve as a reservoir from which the city may be supplied directly by gravity, but as a rule a **pumping station** is necessary. When water is to be used at a place as high as its source, or higher, it must be pumped to a **reservoir** or *standpipe*, sometimes to both. Many river and lake supplies are so impure that the water must pass through settling basins and then be filtered, before it is safe for domestic use; sometimes the water is made fit for use only by subsequent chemical treatment.

Power pumps. The pump most commonly seen at pumping stations is the **double-action force pump** driven by steam power. The operation of this can readily be understood from Fig. 319. This pump is

powerful and delivers a fairly steady stream. It is capable of lifting water to high elevations. For low lifts, such as drawing water from a river to the settling basin along the bank of the river, **centrifugal pumps**

FIG. 318. — The standpipe is at a higher level than the tallest building it supplies.

may be used. These pumps deliver a large volume of water, but do not raise it to a great height. The centrifugal pump has blades attached to the hub of the rotor. As the rotor is driven, suction is created around a center where the inlet pipe is attached. Atmospheric pressure lifts water into the pump. The rotating blades then whirl the water toward the outside of the blades, whence it leaves through the discharge pipe. The pump somewhat resembles an electric fan enclosed in a metal case, or better, perhaps, a water wheel driven backwards. Some types of **rotary pumps** can lift water to high elevations, or from very deep wells. For an individual supply in the country a pump and storage tank is often used. Small lift pumps and force pumps may be driven by windmills, gasoline engines, diesel engines, or electric motors.

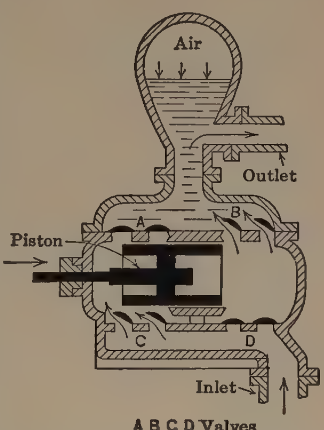


FIG. 319. — Double-acting force pump used in water-pumping stations.

Water pressure. The pressure in any house depends upon the difference in level between the house and the standpipe or reservoir supplying water. If the water in the reservoir is 100 feet above the faucet, we may expect the pressure due to the weight of a column of water 100 feet high, or about 40 pounds per square inch. This is enough to run small water motors for polishing or grinding, and for washing machines. In apartment houses, the pressure varies with the floor, being lowest on the top floor and highest in the basement.

The pressure at any given faucet may be decreased when much water is being used at the same time by others who draw from the same service pipe. Some sections of hilly cities are so high that water from the reservoir will reach only the lower floors. Running water may be supplied to the floors above by means of a private pumping system with a storage tank.

The siphon. When one end of a pipe or tube filled with water is placed in a vessel of water and the other end is held outside the vessel at a level lower than the surface of the water in the vessel and then is opened, water will run out of the vessel through the tube. This device by which a liquid is carried over an elevation and then discharged at a lower level is called a *siphon*. In the diagram it is readily seen that the water column AB balances CD. If the outside end of the tube is raised to the point D, water will stop running; if carried above D, it will run back into the jar. The column of water DE is an unbalanced force acting downward and causes water to run out of E by action of gravity. The pressure in the tube $ABCD$ is reduced by action of column DE, and atmospheric pressure on the surface of the water in the vessel forces more water into the tube. Thus, by continued action of the column DE running out and atmospheric pressure pushing water in, the siphon continues to carry water. The limit of height over which water can be moved by a siphon is determined by atmospheric pressure. At sea level it would be just under 34 feet.

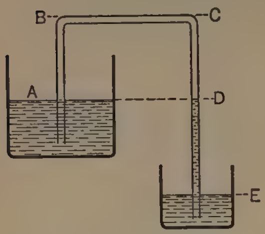


Fig. 320. — The siphon.

Uses of siphons. On a camping trip you may wish to draw gasoline from the automobile tank to supply a gasoline cooking stove. Three feet of rubber tubing will make this a simple task. But remember that the tube must be filled first. Instead of sucking gasoline into the tube, lower the tube slowly into the tank until only a few inches are above the opening, then pinch the tube tightly and draw over the edge of the tank until the end is about a foot below the tank. Unless the tank is nearly empty, gasoline will run from the tube as soon as pressure is released.

Many traps in the plumbing system use the siphon principle in discharging water, and an inverted siphon to form a seal which prevents a flow of sewer gas back into the house.

Household water fixtures. In the piping of a house for water, there are many details which, if not properly attended to in advance, may always be a source of annoyance. One of these is the location of faucets. Outside faucets on opposite sides of the house, and one in the

basement or cellar, will be found convenient. There should be one **main cut-off** by which all the water can be shut off from all the pipes. There should be a cut-off for each outside faucet, to be used in cold weather. It is also an advantage to have a cut-off for each of several different divisions of the water-pipe service, so that when repairs are being made it will not be necessary to shut off the water from all the house.

When water runs from an open faucet, a long stream of water is in motion through the pipe. This moving water has such momentum that, if the faucet is quickly closed, the sudden check on the water produces

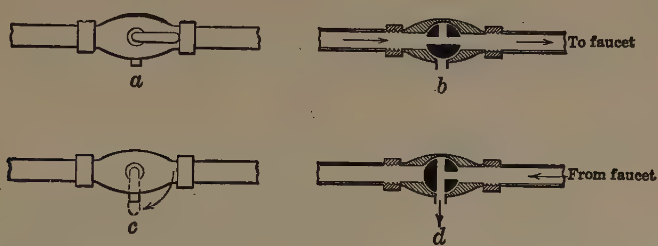


FIG. 321. — How the cut-off valve shuts off the water and drains the pipe to the faucet at the same time.

an unpleasant sound in the pipes, known as *water hammer*. If "dead end" pipes, filled with air, are provided in suitable places, the force of the moving water will be used up in compressing the air in these ends and all annoyance will be avoided.

The flow of water from the pipes is controlled by means of faucets. There are two common types, both of which have proved very satisfactory: they are the **screw type** and the **spring type**. In both of these the opening is closed by a leather or composition washer. By turning the handle of the screw faucet or pressing the handle of the spring faucet, the washer is moved away from the opening. This allows water to flow. When the washer is worn thin or becomes loosened, it will vibrate as the water runs out. Sometimes the thread of the screw faucet becomes so worn that it is loose and vibration is caused. Vibration from either of these sources produces sound which is extremely annoying. New washers will remedy the difficulty in one case, but if the screw threads are loose, it will be necessary to have entirely new faucets in order to remove the trouble.

Automatic sprinklers. Water, a universal fire extinguisher, can be automatically turned on when a fire warms the air to a temperature of 150 to 180° F. The device for doing this is called the automatic

sprinkler head. An opening in the water pipe is closed with a metal disc and cap. These are held tightly covering the opening by a pair of levers, which in turn are held in place in a frame by a two-piece metal link, soldered together with a solder which melts at a low temperature. If the solder has a melting point of 180° F., then, when the air around it reaches that temperature, the solder melts, the parts of the link separate, and the water pressure on the short arm of the lever pushes the metal disc and cap off. Immediately an umbrella-shaped spray of water issues, which will extinguish a near-by fire. You will find these sprinklers in schools and factories, and they are desirable in cellars, where many fires originate.

FIG. 322.—Automatic sprinkler.

The flush tank. The closet flush tank has a type of faucet called a float valve (D), Fig. 323, which is automatic in its action. It is controlled by a floating hollow ball (C) which acts upon a lever arm to open and close the valve. When the flushing lever (A) is turned the outlet valve (H) is opened by raising it. Then the water leaves the tank rapidly. When the water level goes below the top of the outlet valve ball (H), the ball sinks and closes the outlet. The ball float (C) drops as the surface of the water is lowered, and in so doing opens the inlet valve. It then rises with the rising water and can be adjusted to shut the water completely off at any desired level. E is a safety overflow pipe which will carry the water off if by accident the inlet valve should fail to close. The bowl is flushed by many streams around the

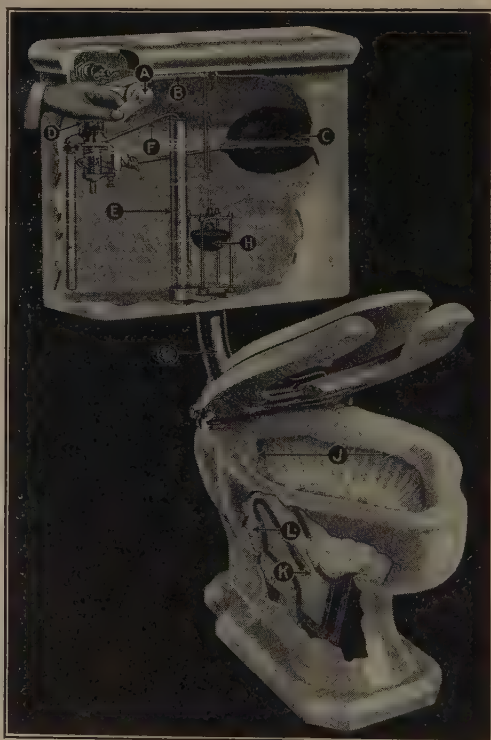


FIG. 323.—The flush tank and bowl.

sides (J). A strong upward jet of water at K, which bends and flows downward at L, starts a siphonic action which quickly empties the bowl. The discharge pipe leads into the sewer, or in a country home perhaps to a septic tank. The repairs most needed will be a new valve ball (H) when that allows water to leak out around it and a new ball float (C) when that becomes corroded so that it leaks.

The septic tank. Many country homes without the advantage of city sewerage build septic tanks to which running water carries the household waste. The septic tank is usually a water-tight concrete tank of at least two compartments. Openings are covered, but allow occasional cleaning. Sewage enters compartment A. Soon a greasy

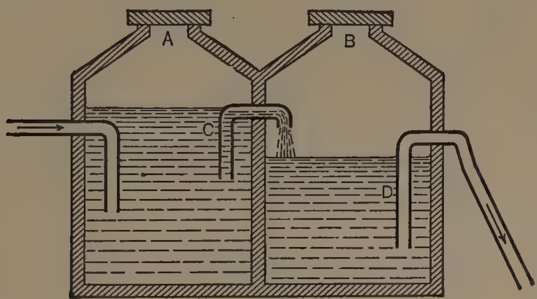


FIG. 324.—A septic tank.

scum covers the surface of the liquid and excludes the air. The solids in the sewage are attacked by the *anaerobic* bacteria. These bacteria work best when air is absent. It is due to their action that the solids in the sewage are liquefied. The liquids are carried over to compartment B through pipe C and are periodically discharged through siphon D. The overflow from B may be run out upon the surface of the land at a lower level or into drainpipes where it is absorbed by the surrounding soil. Oxidation takes place when air reaches it and renders the product harmless.

SUMMARY

1. The source of the water used in the household is rain. This is true whether we have a cistern or a well, or draw our supply from springs, rivers, or lakes.

2. The surface of the ground water is called the water table. The level of the water varies with the amount of rainfall.

3. An artesian well is made by tapping a porous layer which lies deep in the earth below an impervious layer. The water works its way

along this layer from some distant place where the porous layer is open to the surface and can receive rain water.

4. Springs result when the water table reaches the surface on a hillside, or when a crack in an impervious layer allows water from below to rise through it and come to the surface.

5. The house is supplied with water by gravity when the source is higher than the house. Otherwise water is usually pumped.

6. The suction pump, by a series of valves, produces a vacuum into which atmospheric pressure forces the water. The water is then raised by a moving piston to the desired elevation.

7. The force pump, by an arrangement of valves slightly different from that in the lift pump, forces a column of water to a great height. An air dome joined to the delivery pipe makes a continuous flow possible.

8. The common spray pump works on the principle of the atomizer. A strong air jet across the mouth of a second tube, which extends into a liquid, creates suction, so that atmospheric pressure sends the liquid up the second tube and the air current spreads it in a fine spray.

9. The hydraulic ram is a device for automatically lifting water to a higher level than the source.

10. Air pressure in a closed tank will distribute water to all parts of a building. The air pressure is secured by compressing the air above the water, by pumping more water into the tank.

11. Double-acting force pumps, driven by steam, are used in water-supply pumping stations.

12. The water pressure in a city water system depends upon the elevation of the reservoir or standpipe above the place where the water is used.

13. The water system in each house should have several cut-off valves, in order that the water may be cut off from certain parts of the house or from the entire house, when it is necessary to repair faucets, tanks, or connections.

14. Two important types of faucets are the screw type and spring type. The dripping of water from a faucet can usually be stopped by placing a new washer in the faucet.

15. The action of the automatic fire sprinkler depends upon the melting of fusible metal which opens a water pipe at a temperature a little above ordinary maximum room temperature.

16. By means of a siphon a liquid may be carried over an elevation and discharged at a lower level. The tube must be filled with liquid and the open end held at a lower level than its source. The unbalanced column of liquid in the long arm starts the action.

17. The flush tank has an automatic control for water supply. Most bowls use the siphon principle in discharging.

18. The septic tank renders sewage harmless through the action of bacteria.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Underground waters.
2. Ancient water systems.
3. The local water-supply system.
4. Make a model pump.
5. Water power.
6. The city sewerage system.

CHAPTER XXIII

HOUSEHOLD MEASUREMENTS

Weight. All bodies on or near the surface of the earth are attracted to the earth with a force which is proportional to the **mass** of the body, that is, the *quantity of matter in the body*. We speak of the force that draws a body toward the center of the earth as the *force of gravity*. The measure of this attractive force is called **weight.** The weight of a body varies slightly at different parts of the earth and is less if the body is carried high above or far below the surface of the earth. A given body weighs most on the surface of the earth, and at the poles. The point in a body at which we may regard all the pull of gravity, *i.e.*, the weight, as acting, is the **center of gravity** of the body.

Gravity is but a special example of the **law of universal gravitation**, namely, that *all particles of matter in the universe attract each other* with a force that varies inversely as the square of the distances between them and directly as the product of the masses.

The attraction between the earth and the bodies at its surface is mutual, but because of the enormous mass of the earth, we usually speak of the earth as pulling a falling body to it, though it is true that the earth is pulled toward the falling body to an infinitesimal extent.

Units of measure. In order to measure anything there must be some definite quantity, called a *unit*, with which to compare the quantity to be measured. Units for measuring length, volume, and mass are arbitrarily agreed upon. Certain units have been adopted as standard units of measure by the government. The standard measures are all in charge of the National Bureau of Standards at Washington.

Two systems of measurements are legal in the United States:

The **English system**, employing such units as the pound, foot, quart, gallon, and bushel, is common in commerce.

The **metric system** is used in practically all scientific work, and to some extent in commerce.

Metric system of measurements. The simplicity of the metric system results from its being based on the decimal system. Comparison of similar units in the two systems shows the great advantage of the metric system.

1 mile = 320 rods = 5280 feet = 63,360 inches.
1 kilometer = 1000 meters = 100,000 centimeters.

In the United States money is reckoned by the decimal system, but our system of weights and measures is cumbersome, inconvenient, and

FIG. 325. — Household measuring devices (*Bureau of Standards*).

time-wasting. Great Britain and the United States are almost the only countries that have not adopted the metric system.

All metric units are based upon the unit of length, the **meter.** It was originally intended to make the meter one ten-millionth of the quadrant of the earth's meridian, but an error was made in measuring this meridian, and since the error was not discovered until after the meter had been adopted as a standard, it was decided not to change the length of the meter. The **standard meter** is the distance between two lines on a platinum bar preserved in Paris.

TABLE XXV

Metric-English Equivalents

1 cm.	= 0.3937 in.	1 in.	= 2.54 cm.
1 m.	= 39.37 in.	1 ft.	= 30.48 cm.
1 m.	= 3.28 ft.	1 ft.	= 0.305 m.
1 km.	= 0.621 mile	1 mi.	= 1.609 km.
1 gm.	= 0.035 oz. (avoir.)	1 oz.	= 28.35 gm.
1 kgm.	= 2.2 lb. (avoir.)	1 lb.	= 453.6 gm.
1 sq. cm.	= 0.155 sq. in.	1 sq. in.	= 6.45 sq. cm.
1 cu. cm.	= 0.061 cu. in.	1 cu. in.	= 16.39 cu. cm.

1 liter = 1.0567 U. S. liquid quarts = 0.9081 U. S. dry quart = 61 cu. in.
1 carat (for precious stones) = 200 mg.
15 grains = 1 gm.

The unit of weight in the metric system is the **gram,** which is the weight of 1 cubic centimeter of pure water at 4° C. The unit of volume is the **liter,** which is the volume of 1000 grams (1 kilogram) of pure water at 4° C. A liter is slightly more than a quart.

TABLE XXVI

Miscellaneous Values

1 roll (wall paper) = 36 sq. ft.	1 cu. ft. ice weighs 57.5 lb.
1 bolt (cloth) = 40 yd.	30 cu. in. ice weigh 1 lb.
1 cu. ft. water weighs 62.4 lb.	1 board foot = 144 cu. in.
1 cu. in. water weighs 0.036 lb.	1 gallon water weighs 8.34 lb.

1 carat (fineness of gold) = $\frac{1}{24}$ gold by weight
1 cu. ft. air (at standard conditions) weighs 0.0817 lb.
1 cord = 128 cu. ft. Cord wood is understood to be 4-ft. lengths
"Sawed" wood in some states is reckoned 110 cu. ft. to cord in tiers but 160 cu. ft. in a loose heap

Average Weight Anthracite Coal in *pounds per cubic foot*

Color of Ash	Egg	Stove	Nut	Pea	Buckwheat
White	57.0	56.5	55.5	53.5	53.0
Red	53.0	52.5	52.0	51.0	50.5

Household balances. Two types of balances are in common use. Both of these are found in stores, and both are suitable for the home. The **beam balance,** which operates on the lever principle, is very reliable. It may have equal or unequal arms. In the more common form, the **equal-arm balance,** the pointer or index is brought to its proper position when the weights in the two pans are equal. The **steelyard,** once in almost universal use, is an example of an unequal-arm balance. The object to be weighed is hung from the hook or placed in a pan supported from the short arm, and is then " balanced " by sliding the small counterweight provided along the long arm. In the practical instrument, the counterweight balances the steelyard with suspended pan, when hung from the " zero " notch. The long arm is then graduated from this " zero," each notch being marked with the weight of the object on the pan or hook, which is balanced by hanging the counterweight from that notch, so that no calculation is necessary.

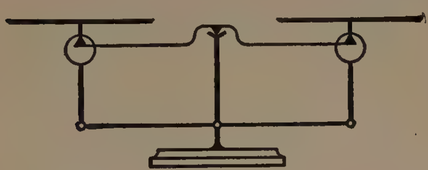


Fig. 326.—An equal-arm balance.

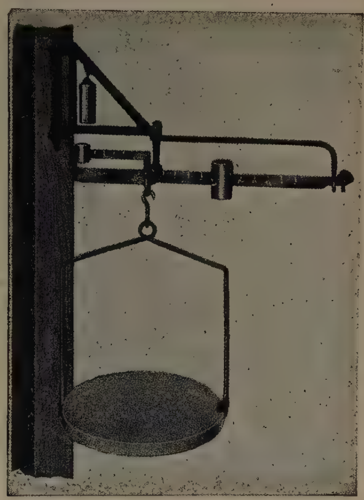


Fig. 327.—Suspension balance; steelyard type.

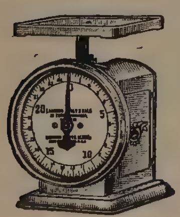


Fig. 328.—Household scale; spring type.

The spring balance. The principle on which the spring balance works is simply that the force required to elongate a coiled spring is, within the limits of elasticity, proportional to the amount of elongation. If 1 pound of force stretches a coiled spring $\frac{1}{2}$ inch, 2 pounds will stretch it 1 inch, and 6 pounds, 3 inches. It is thus an easy matter to make a scale over which a pointer moves so that the weight is registered while it is on the scale pan. Either one or two springs give satisfactory results.

Measuring common commodities. Liquid commodities for household use may easily and accurately be measured by volume. This is

not equally true of dry commodities, especially of coarse articles. Accurate measure of the amount of dry articles is possible only by weighing them. Several states now require that dry commodities be

Fig. 329. — These two measures have the same capacity, but the one with the small diameter gives short measure by the amount overflowing on the table.

sold by weight; in other states they may be either measured or weighed. Greater uniformity in the law for different localities, and in the legal weight of certain common volumes, as for example the bushel and the peck, is greatly to be desired. Fraudulent dry measures are very easily prepared and used.

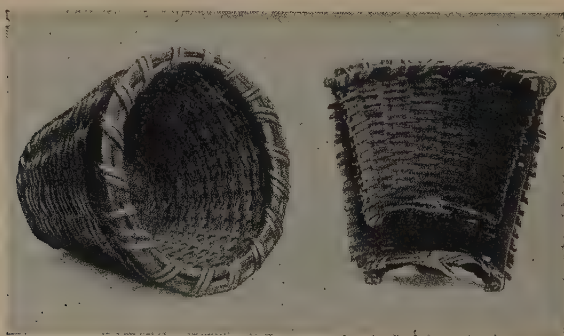


Fig. 330. — A reason why some purchases need to be checked by the purchaser.

Table XXVII gives in convenient form the equivalents of common volume units frequently used in the household.

Density and specific gravity. The **density** of a substance is the *weight of a unit volume* of it. The density of water is 62.4 pounds per cubic foot or 8.34 pounds per gallon. In metric units, water has a

density of 1 gram per cubic centimeter. When densities are expressed in grams per cubic centimeter, the figures representing the densities also indicate the *relative weights* of unit volumes of the substance and water. For example, iron has a density of 7.5 grams per cubic centimeter; hence we know that, volume for volume, iron weighs 7.5 times as much as water, and we may calculate the weight of a cubic foot of iron by multiplying 62.4 by 7.5. The numerical ratio of the density of

TABLE XXVII

EQUIVALENTS OF THE COMMON CAPACITY UNITS USED IN THE KITCHEN

Units	Fluid Drams	Teaspoonfuls	Tablespoonfuls	Fluid Ounces	Gills (½ Cupfuls)	Cupfuls	Liquid Pints	Liquid Quarts
1 fluid dram equals	1	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	$\frac{1}{256}$
1 teaspoonful equals....	$1\frac{1}{3}$	1	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{24}$	$\frac{1}{48}$	$\frac{1}{96}$	$\frac{1}{192}$
1 tablespoonful equals..	4	3	1	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$
1 fluid ounce equals....	8	6	2	1	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
1 gill (½ cupful) equals..	32	24	8	4	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$
1 cupful equals........	64	48	16	8	2	1	$\frac{1}{2}$	$\frac{1}{4}$
1 liquid pint equals	128	96	32	16	4	2	1	$\frac{1}{2}$
1 liquid quart equals ...	256	192	64	32	8	4	2	1

a substance to the density of water is the **specific gravity** of that substance. Thus, 7.5 is the *specific gravity* of iron, but the *density* of iron is 7.5 *grams per cubic centimeter.*

The specific gravity of cork is 0.25. Anything lighter than water will float, because the water buoys it up. A cubic foot of cork weighs 15.6 pounds, while a cubic foot of water weighs 62.4 pounds. It is therefore possible to load a cubic foot of cork with 62.4 — 15.6, or 46.8 pounds, before it will sink in water. This explains the value of cork in life preservers.

Hydrometers. Advantage is taken of the buoyant effect of liquids upon floating objects in determining the specific gravity or density of liquids. A body that floats partly submerged in water will sink deeper if placed in a less dense (" lighter ") liquid, and rise higher out of the liquid in a denser (" heavier ") liquid. This happens because a *floating body always displaces a weight of the liquid equal to its own weight.* By arranging a suitable scale on the floating body by which to observe the level of the liquid, and by weighting the body so that it will always

TABLE XXVIII

DENSITIES (APPROXIMATE AT 68° F.)

In grams per cubic centimeter

Solids		Liquids — *Continued*	
Gold	19.3	Brine (5% salt)	1.035
Lead	11.4	Brine (25% salt)	1.191
Copper	8.9	Cider vinegar	1.0114
Iron	7.4–7.8	Sirup (maple)	1.33
Aluminum	2.6	Milk	1.03
Cork	0.25	Cream (18% fat)	1.01
Glass	2.4–4.5	Cream (40% fat)	0.99
Human body	0.9–1.1	Gasoline	0.72
Butter	0.86	Kerosene	0.80
Lard	0.92	Alcohol	0.79
Tallow	0.95	Olive oil	0.91
Ice at 0° C.	0.917	Mercury	13.6
Oak charcoal	0.58	Glycerin	1.26
Pine	0.65	Sulfuric acid	1.84
Oak	0.75	Storage battery acid (charged)	1.28
Ebony	1.2	Turpentine	0.87
Liquids		**Gases**	
Pure water at 4° C.	1.00	Air (dry)	0.00120
Sea water	1.025	Air (50% humidity)	0.00119

The *relative* densities of common gases are:

Air	1.	Carbon dioxide	1.53
Oxygen	1.1	Hydrogen	0.07
Nitrogen	0.97	Helium	0.28

float in a fixed position, the density of any liquid may be compared with that of water as a standard. Such special instruments are called **hydrometers.** One common type is shown in Fig. 36. The scale may be graduated to read specific gravity, per cent, or any arbitrary numbers.

The reading of the hydrometer should always be made with the eye on a level with the surface of the liquid. When great accuracy is desired, the test must be taken at a specified temperature, because the density of a liquid changes slightly with temperature. Can you tell why?

Meters. Our supplies of gas, electricity, and water are available at all times, usually in such quantities as we desire; and yet only exceptionally do we store them on our premises as we do our coal, wood, oil, or gasoline. Bottled "gas," however, may be obtained for the rural home when no piped gas is available. We may see the coal and oil measured, and a definite amount may be delivered to us to be stored

for use; but gas, electricity, and water are measured only as they are consumed. Meters for measuring gas and electricity are permanently installed and register the quantity that passes through them. In many communities water meters are also permanently installed.

The gas meter. The gas meter receives the gas from the service pipe and records in cubic feet the quantity of gas that passes through it into the consumer's pipe. Since the gas delivered is at a pressure above that of the atmosphere, it is able to do work. Gas is therefore applied to operate the mechanism of the meter and it records its own volume. The gas meter is a gas-tight metal box, Fig. 331, having a gas entrance

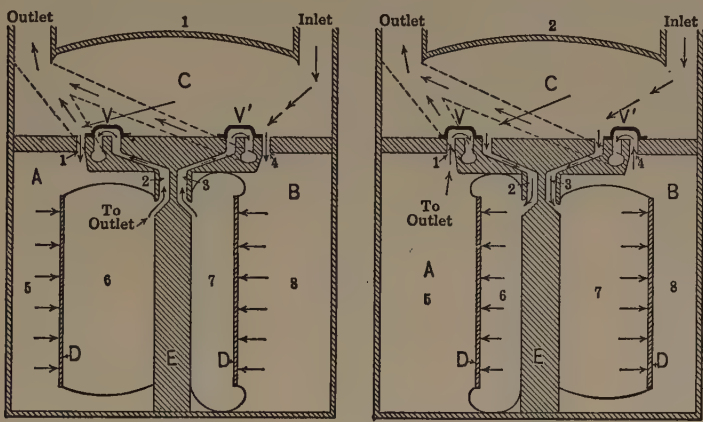


FIG. 331. — Section of the gas meter.

chamber C at the top where the slide valves are operated, and two small chambers, A and B, below. The chambers A and B are exactly alike. They each contain a metal diaphragm D, which is attached by means of flexible accordion-pleated sheepskin to the fixed central partition E. The diaphragms D are thus free to move out or in, depending upon the direction of greatest pressure.

When the gas cock is open, gas flows through the meter and the following action takes place: Gas enters the chamber C through the inlet from the gas main. Gas passes through the ports 1 and 4 into the spaces 5 and 8. Ports 2 and 3 are now connected with the outlet pipe by means of the slide valves V and V'. Incoming gas is pressing against the diaphragms, and this greater pressure pushes the gas in 6 and 7 into the outlet pipes. Just as the diaphragms are moved to the left as far as they will go, the slide valves are moved over to connect 1 and 4 with the outlet pipes. This permits the gas at the main pressure to come to 6 and 7 through the ports 2 and 3, thus pushing the

diaphragms outward. The gas in 5 and 8 is now pushed through 1 and 4 into the outlet pipe. Since the diaphragms are moved a fixed distance each time, the volume of gas is accurately measured. The volume of the gas is recorded on an index which is connected with the diaphragms by levers. The diaphragms are attached to a long vertical rod, and, as they move out and in, they turn the rod in the upper part of the meter. This backward and forward rotary motion of the rod is transmitted by suitable lever arms to give rotation in one direction and, by means of wheels, records the amount of gas on the index. These same lever arms shift the slide valves. One valve closes the port one-fourth of a rotation ahead of the other in order to insure an even flow of gas. All this mechanism may be examined on a discarded meter which has been opened at the sides and top.

Reading the gas meter. The common index of the house meter has three recording dials on which the gas consumed is recorded. There is also a small dial at the top with a scale representing two or more cubic feet. This is used in testing the meter, and may be read to observe a small amount of gas in an experiment. Each pointer on the three large dials moves according to the arrangement of gear wheels in the works.

When a new meter is installed, all the dials read zero. The pointer of the dial at the right moves one space for each hundred cubic feet of gas consumed. In the same time the middle pointer has moved one-tenth of a space, and the pointer at the left, one-hundredth of a space. When the right-hand pointer has made one complete revolution, it records 1000 cubic feet, and the middle pointer is on figure 1. When the middle pointer has made one complete revolution, the right-hand pointer has moved entirely around ten times, and the left-hand pointer has moved one space. The reading then would be 10,000 cubic feet. It will be observed that the middle pointer turns in a counterclockwise direction, while the other two turn clockwise.

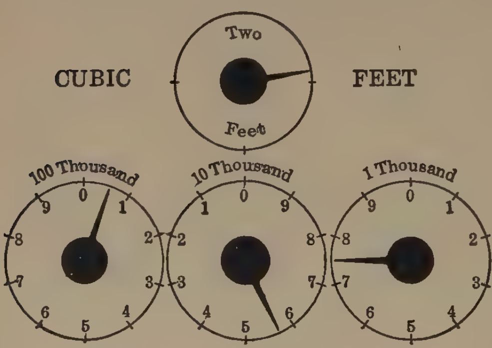


FIG. 332. — Gas meter index.

In reading a meter, begin at the left dial and read each dial in turn, recording the number that the pointer has last passed. This will be the number of hundred cubic feet of gas which the meter registers. The

amount of gas used in a given period is found by subtracting the meter reading taken at the beginning from the reading taken at the end of the period.

Most beginners find it difficult to read the meter when one of the pointers is apparently just on one of the figures, but the pointer next to the right is somewhere between 8 and 10. When a pointer is around 8 or 9 it has not quite completed the circle and therefore the next pointer to the left cannot have traversed a complete space. Hence, in reading a pointer which is close to a figure, the reading of the pointer on the dial to the right must be considered before deciding what the reading is.

Prepayment meters. Prepayment meters differ from the common meter only in having an added device by which the gas is shut off after the quantity paid for has been used. These are usually fitted with a slot to receive a quarter of a dollar. After a quarter has been inserted the lever is turned. This acts upon a set of gears and advances a metal rod along a threaded screw. If the gas is off, this opens the pipe and also moves an indicator along a scale which can be seen on the front of the meter. Several quarters may be inserted, one after another, the lever being turned each time. When gas passes through the meter, the same shaft that turns the wheels of the meter dials also turns the threaded screw upon which the metal rod was advanced. The turning screw pushes the metal rod back, and when it reaches the starting place it closes the gas inlet.

The electric meter. The electric kilowatt-hour meter, found in the home, is a device which uses a minute fraction of the current coming to the house to run a small motor. The revolving part of this motor operates the dial hands by means of interlocking gears. The amount of energy passing through the motor is always in proportion to the amount of energy being consumed in the house. It is therefore possible to have such a combination of gears that the dials will register the amount of electrical energy consumed.

The recording index of the house meter usually has four dials. The first dial (right) reads up to 10 kilowatt-hours, and the fourth (left) to 1000 kilowatt-hours. The rule given for reading dials of the gas meter applies to reading the electric meter.

The water meter. The common house water meter is of the disc type. A flat, hard-rubber disc is attached at its center to a sphere whose axis is perpendicular to the disc. On one side, the disc is slotted from its outer edge to the center sphere. This slot fits a partition which is between the inlet and outlet of the measuring chamber. The measuring chamber, Fig. 333, is the central part of a sphere. The axis of the disc is inclined some 20° from the perpendicular. As water

enters the chamber and presses, say, upon the upper surface of the disc, it keeps crowding its way farther and farther along, pushing the

Fig. 333. — The measuring chambers of the water meter.

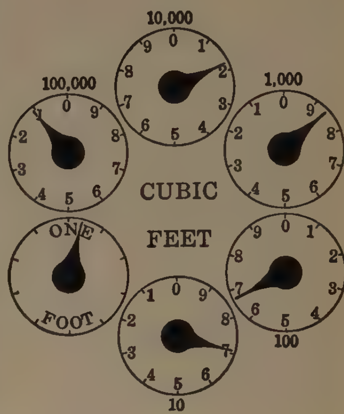


Fig. 334. — Water meter index.

disc down until finally the under surface of the disc becomes exposed to the inlet. Then incoming water pushes upon the disc, forcing all the water on the other side of the disc out through the outlet pipe. The quantity of water admitted each time just fills this space and, by proper connection of the rotating axis with geared wheels, the quantity of water which is passed through the meter is recorded. The ratio of gears is such that the dials, Fig. 334, record gallons of water. The reading of the meter is not different in principle from that of the gas meter or the electric meter.

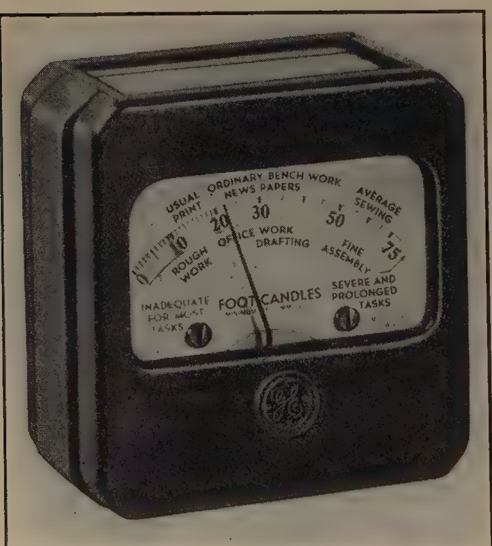


Fig. 335. — The light meter.

Measurement of illumination. The important thing about light measurement is to know how strong the light is at a given place where it is being used. For this a light meter is used. Its scale gives readings in foot-candles. In a recently developed light meter the light-sensitive cell consists of a layer of selenium coating a steel plate. Transparent layers of metal are deposited over the layer of the selenium. This makes a photoelectric cell; it is slightly more than 1 square inch in area. Light falling upon the selenium produces an electric current

FIG. 336. — Light meter in use.

which is conducted through a microammeter. A scale gives readings in foot-candles; it has a range from 0 to 750 foot-candles. The light meter measures illumination from one direction. It gives correct readings for direct light, but if much light comes from various angles a slight correction is needed. The readings are correct for electric lights but need reduction of 20 to 30 per cent in daylight.

Early measurement of time. The first measurement of time was a rough division of the day by the position of the sun and the length and position of shadows. Then came the **sundial,** which was in use in China as early as 1100 B.C. **Water clocks** were in use about the fifth century B.C. These had one decided advantage over the sundial in

that they could be used at all times, whereas the sundial was of no value except when the sun was shining. The **hourglass** works on much the same principle as the water clock, but falling sand replaces the water. The hourglass was first used in the eighth century A.D. It still finds use as a "three-minute" glass to time the "boiling" of an egg. **Clocks** are traced back to the fourteenth century, although it was much later that they became cheap enough to be common.

The sundial. Sundials are now made for their artistic value rather than their usefulness. A study of Fig. 337 will show you why the *style* of the sundial must be inclined a number of degrees equal to the latitude of the place where the dial is to be used. *OP* is a line parallel to the earth's axis, *P* represents the polar star, *S* and *W* represent the midday sun in summer and in winter respectively. *S′* and *W′* represent the sun at 10 A.M. in summer and in winter. If the style of the dial were vertical (*VO*), the summer and winter sun would cast a shadow due north in both cases, but the winter sun at 10 o'clock would cast a shadow *OC* and the summer sun *OD*. If, however, the style is inclined so that its upper edge points towards the North Star (*V′O*), the position of the shadow cast by the style at any given hour will be the same during the entire year. As sun time may be fast or slow in comparison to our clocks, which register mean solar time, the sundial seldom gives us correct time. Its greatest variation from mean solar time is about sixteen minutes.

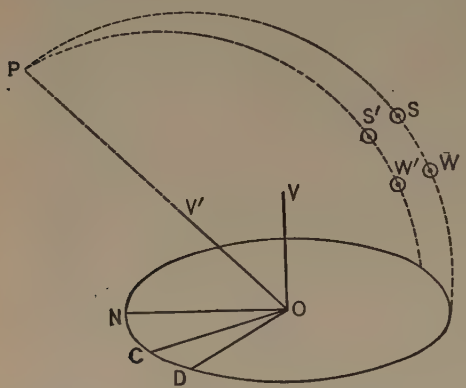


FIG. 337. — The style of the sundial (*V′O*) must point toward the north star.

Household clocks. Two types of clocks are in use today, the **pendulum type** and the **balance-wheel type.** The power to drive the wheels is derived from the *mainspring,* although in some old-fashioned clocks weights are used as they were in the earlier clocks. The pendulum clock must be kept upright. This is not necessary with the balance-wheel clock or the watch, which is of the same type. The purpose of the pendulum or the balance wheel is to obtain uniform speed. Working with these is a very important device known as the escapement. It is through this that the pendulum or the balance wheel controls the speed of the train of wheels in the works of the clock.

It is also through these that the mainspring gives the force which keeps the pendulum and the balance wheel from stopping.

The simple pendulum. The simplest pendulum we can devise consists of a weight suspended by a fine thread. At rest it hangs vertical. If pulled aside and released, it swings back and forth, the momentum

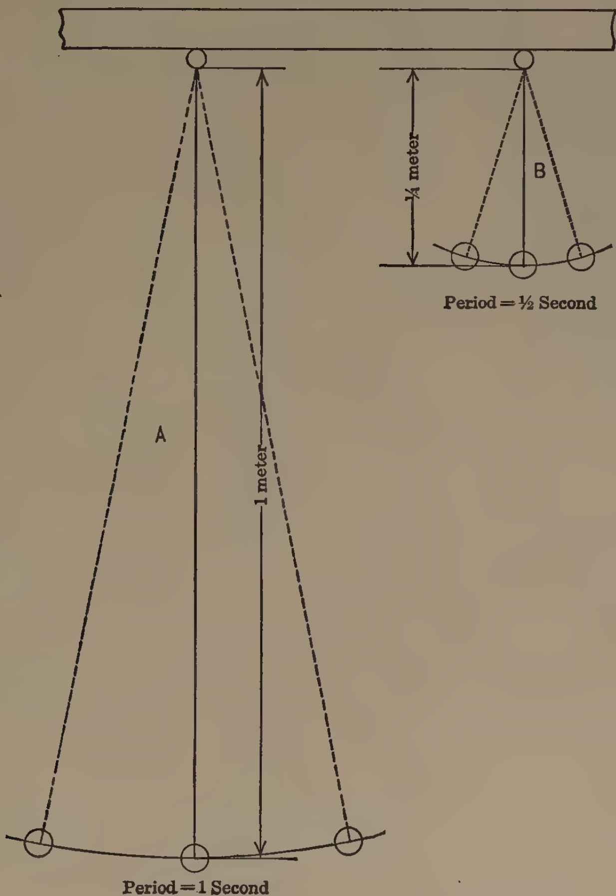


FIG. 338. — Pendulums.

gained in falling from its elevated position at one side to its lowest position being sufficient, were there no friction, to raise it to the same elevation on the other side. Even with friction it will continue to vibrate for a long time. Galileo was the first to observe that each swing of a swinging body consumed the same period of time. He timed the swinging lamps in the cathedral of Pisa, using his own pulse

to measure the duration of the swing. The application of this discovery to time-keeping devices is at once apparent. Another fact easily demonstrated is that the time of the swing, called the **period** of the pendulum, *varies as the square root of the length of the pendulum.* A pendulum 1 meter long makes 1 vibration in 1 second, but a pendulum $\frac{1}{4}$ meter long has a period of $\frac{1}{2}$ second.

$$P_a : P_b :: \sqrt{l_a} : \sqrt{l_b}$$

therefore

$$1 : \tfrac{1}{2} :: \sqrt{1} : \sqrt{\tfrac{1}{4}}$$

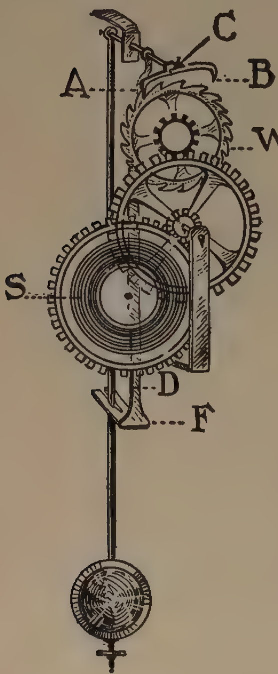


Fig 339. — How the escapement and pendulum work together.

The pendulum clock. The really successful clock came about the year 1700. It resulted from combining the falling weight for power, the swinging pendulum (Galileo's discovery) for regularity of motion, and the *dead-beat escapement* invented by George Graham, to prevent the pendulum from coming to rest. The escapement consists of a toothed wheel W and a rocker arm ACB, Fig. 339. The inside of pallet A and the outside of pallet B coincide with the arc of the circle of which C is the center. The falling weight or, in modern clocks, the spring, causes the wheel W to turn.

The pendulum is usually suspended by a thin flat spring. At some place along the pendulum rod a contact is made with the pronged fork F, which is joined to the escapement rocker C by the rod D. As the pendulum swings, rod D swings and turns the rocker so that the projections at its ends alternately catch in the teeth of the escapement wheel W. This is one of a train of wheels driven by the mainspring or weights. The rocker allows but one cog of the wheel to pass during a complete vibration of the pendulum. For the wheel to make one revolution, the pendulum must swing back and forth as many times as there are cogs in the wheel. As each cog escapes from the rocker, a slight impulse is given to it and is communicated to the pendulum, which would otherwise soon cease to vibrate. By the proper relation of the cogs on the various wheels in the clock, the two different speeds for the hour hand and minute hand are secured.

The balance wheel. The balance wheel with spring is another device for securing vibrating motion, equally timed as in the pendulum. Its advantage lies in its compactness; without it we could hardly have watches. In hot weather the wheel increases in diameter and changes the period of vibration. To compensate for changes in temperature, the rim of the balance wheel is usually composed of two parts. One end of each part is joined to a spoke of the wheel, and another end is left free. Each part of the rim is a compound bar so made that as it expands the free ends of the rim bend inward just enough to balance the expansion of the fixed ends. The balance wheel of a watch makes 18,000 vibrations an hour and moves a distance of 18 miles a day.

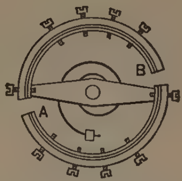


FIG. 340. — Balance wheel.

Compensating pendulums. When the temperature rises and the ordinary pendulum lengthens through expansion, an adjustment may be made to raise the bob. A better plan is to have a compensating pendulum which is so devised that the center of gravity of the bob is always the same distance from the point of support of the pendulum.

One form of the compensating pendulum is the **mercury pendulum**, in which, as the pendulum grows longer, the expanding mercury rises enough to compensate for its lengthening. This is shown in Fig. 341.


FIG. 341. — Compensating mercury pendulum.

Another form is known as the **gridiron pendulum.** The bob is suspended from a combination of steel and brass rods so arranged that the expanding steel tends to lower, while the expanding brass tends to raise the bob. The proportions are such that the length of the pendulum remains constant in spite of temperature changes.

The electric clock. The radio and the electric clock have in recent years given the home the means of keeping accurate time. The common electric clock depends for its action upon a synchronous motor. If the electric plant delivers 60-cycle alternating current, timed with accuracy, then the electric clock made for 60 cycles will keep accurate time. Once set into motion and brought up to the exact speed of the generator supplying the current it will continue to keep in step with it.

The metronome. This is a form of loud-ticking clock without face or hands. The time interval is communicated either by sound or sight. The pendulum of the metronome is unlike the usual clock pendulum in

that it has a sliding bob above its point of suspension. By sliding the bob higher, the metronome is made to beat slower time, and by lowering it, to go faster. The chief use of the metronome is in marking time in music, though it is also useful in marking time for experimental purposes, when it would be inconvenient to look at the hands of a watch.

SUMMARY

1. The different commodities used in the household require a variety of units of measure. Volume is the space a body occupies. Weight is the measure of gravity.

2. There are two systems of measurement: the English, used commonly in England and the United States; and the metric, used commonly in all other countries and everywhere in scientific work.

3. A household balance is useful in checking up small purchases. The beam balance works on the lever principle, and the spring balance on the principle that a coiled spring stretches equally for equal weight.

4. Density is the weight of a unit volume of a substance, and specific gravity is the ratio of the density of a body to the density of water. The hydrometer is a convenient instrument for measuring the specific gravity of liquids.

5. The pressure of gas in the mains supplies the necessary force for operating a gas meter, by means of which the gas is measured and the quantity recorded on the meter index.

6. The kilowatt-hour meter measures electrical energy by using a small fraction of the current to run a motor for making the record.

7. Water is measured in the disc meter by means of a slotted disc which allows a measured quantity of water, alternately above it and below it, to pass from the meter inlet to the outlet. The moving axis operates the recording mechanism.

8. Illumination at any place is easily measured by means of the foot-candle meter. This is a photoelectric cell which changes light energy into electrical energy. The electric current indicates foot-candles on the scale.

9. The sundial, which dates back about three thousand years, was once a common means of marking time during the day, but was of no value except on sunny days.

10. The pendulum clock takes advantage of the fact that each swing of a pendulum consumes an equal period of time. By connecting a pendulum to the escapement rocker of the clock works, uniform speed of the wheels is obtained. Equal-timed vibration may also be secured by means of the balance wheel.

11. The motive power in clocks is usually a coiled spring. In some clocks it is an elevated weight.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Legal weights and measures in the state.
2. Advantages and disadvantages of having the metric system made legal and compulsory in the United States.
3. Learn to read meters.
4. Study the periods of pendulums experimentally.
5. How electric clocks work.

CHAPTER XXIV

MOLECULAR FORCES

A knowledge of the forces acting between molecules helps to explain many processes which are going on every day under our very eyes. In a burning candle, in the welding of two pieces of iron, in the "steaming" of windows, in dissolving salt or sugar in water, in the swelling of beans or prunes placed in water, in the absorption of ink by a piece of blotting paper, in the fragrance of a flower, we have examples of molecular forces. Many properties of matter depend upon these forces.

Molecular motion and states of matter. All molecules are believed to have a vibratory motion which is responsible for the heat energy in a body. In solids, each molecule keeps in one place with respect to surrounding molecules. In liquids and gases, molecules are able to circulate among the other molecules so that their neighboring molecules are constantly changing. The ability to move in this way depends upon the heat energy or the vibration energy possessed by the molecules. There are three states or conditions of matter dependent upon the stored energy in the molecule.

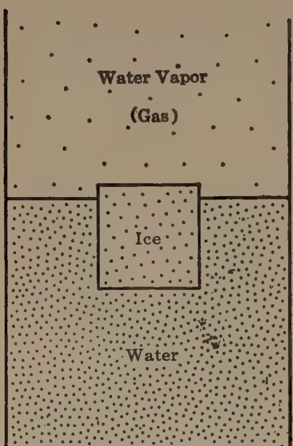


FIG. 342. — The dots represent molecules. Give the reason for the three different conditions shown.

In *solids*, like ice and iron, the molecules vibrate but cannot move around to come in contact with a different group of molecules. This fixed position of molecules gives rigidity to a solid and causes it to resist a change in shape or size. But if heat is applied until the body melts, an additional ability to move is given to the molecules.

In *liquids*, as water and oil, the molecules not only vibrate but move around among the other molecules. Liquids will take the form or shape of the containing vessel, but they resist change in size. If enough heat is applied, eventually the molecules will suddenly separate so that the space between them is much greater than it was in either the liquid or solid state, and the body assumes the gaseous state.

In *gases*, as steam and air, the molecules have greater energy than in liquids. They are hundreds of times as far apart and seem to repel

each other. They move about and collide with one another, but tend to expand and fill any space of any shape into which they are put. To a slight extent, they resist compression.

Melting point. True solids like ice and aluminum remain hard and firm when heat is applied, until they melt. They have a definite melting point at which they suddenly change to a liquid. Lard and butter soften under heat long before they become liquid. Candles and sealing wax when warmed slightly above room temperature for a long time will change shape or even flatten out. When glass is heated in a flame, it softens and is easily bent. In cold weather, tar is brittle, and we may call it a solid. In cold weather, water may be in the form of ice. There is no question about its being solid then. But when heat is applied, at 32° F. the ice suddenly changes to the liquid water. If we warm tar we shall eventually get a product which we are sure is a liquid, but there is no temperature at which it abruptly changes from solid to a liquid. Many substances have no clearly marked melting point. When they are very cold, we feel justified in calling them solid, and when very warm, we call them liquid, but just where the dividing line is between those two extremes is difficult to say. Even molasses varies greatly in the way it flows at different temperatures.

Viscous liquids. By viscosity we mean molecular friction of flowing liquids. Molasses is a viscous liquid. As it is cooled the internal friction of the molecules is increased and therefore its viscosity is increased. Oils are viscous. Lubricating or engine oil is more viscous than kerosene oil. Heat decreases the viscosity of liquids. For this reason, oil for the clock or watch would not do to lubricate the pistons of a gas engine. A soap solution has greater viscosity than pure water. It is because of this that we can blow larger bubbles with soapy water. You can beat the white of egg or whip cream into a frothy mass because of the viscosity that allows the formation of films which hold the bubbles of air.

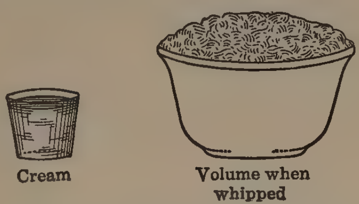


Fig. 343. — Explain the increase in volume when cream is whipped.

Properties of solids depending upon molecular action. Steel cables will hold more than rope cables of the same size because the molecules in the steel offer greater resistance to being pulled apart than the molecules in the rope. This property of resistance to being pulled apart is called **tenacity.** Bodies like copper and silver which are easily drawn into a wire are **ductile.** If, like gold or aluminum, they can be beaten or rolled into very thin sheets, they are **malleable.** A body which

breaks easily when struck a blow is **brittle**; an example is glass. **Hardness** is resistance to scratching. Fresh clay is soft but when baked into brick is hard. When two substances are rubbed together, the one which will scratch the other is the harder. The diamond is the hardest of all substances. Many substances are bent, compressed, stretched, or in some way distorted by a body acting upon them. If, after being distorted, a body returns to its original size or shape it is **elastic.** Steel and glass are more elastic than rubber. They will not stand as much distortion, but within their limits of elasticity they have greater ability to return to their former condition. The elasticity of a coiled spring is utilized in several types of balances for weighing. This is possible because within the limits of elasticity the stretching is proportional to the force applied. A scale is made over which a pointer moves to show the amount of stretching produced by the substance being weighed. It is due to the elasticity of the spring that a watch will run, and the elasticity of the springs under the automobile makes riding comfortable.

Liquids resist forces which tend to compress them, but when confined they will communicate any external pressure that is applied to all surfaces undiminished. You see the application of this in the automobile lift at the filling station. Oil is pushed into a tank under high pressure. The oil presses upward on the under side of the cylinder that lifts the track holding the automobile.

Diffusion of gases. If you spray a little perfume into the air, pour a little concentrated ammonia into a shallow dish, or open the gas jet for a few seconds, persons in another part of the room can soon detect the odor. The molecules of these gases will have made their way through the intermolecular spaces in the air to the distant parts of the room. Any two gases brought into contact will mix by a process called "diffusion." Even gravity will not prevent this, for it is found that, if hydrogen, the lightest of all gases, is placed at the top of a jar and carbon dioxide, a heavy gas, at the bottom, in a short time there will be an even distribution of the gases throughout the cylinder. Hydrochloric acid gas has twice the density of ammonia gas. When the two come together, they produce white particles of ammonium chloride. If a jar of the light gas, ammonia, is placed mouth down over a jar of heavy gas, hydrochloric acid, it is easily demonstrated that particles of hydrochloric acid go to the top jar and particles of ammonia go to the bottom jar, soon filling both jars with the white product which can be produced only when the two unlike molecules unite. The molecules are so far apart in gases that they can move long distances without colliding with each other, and so diffusion in gases is rapid. If a cloth

wet with concentrated ammonia is supported on the lecture table, the gas will mingle with the air and may be evident a considerable distance away by its odor. If another cloth is wet with concentrated hydrochloric acid and placed several feet away from the cloth wet with ammonia, the two gases will soon meet in the air. Evidence of this is the white cloud of ammonium chloride which they form. The fragrance of flowers is due to gases given off by the flowers mixing in the air we breathe. The diffusion of gases is one of the evidences that matter is made up of tiny particles which we call molecules. The air we breathe is kept uniform in composition by this process of diffusion. When gas escapes from the gas range or burner, it does not keep in a body by itself but mixes with the air. This causes it to be exceedingly dangerous when the proportions are within the explosive range (7 to 15 per cent illuminating gas). Camphor, naphthalene (moth balls), and iodine are solids which will slowly evaporate or change to a gas without becoming liquid. It is the diffusion of the vapor of camphor and naphthalene throughout a closed chest that makes them moth-repellent. The amount of these volatile solids which will vaporize in a given space is determined by the temperature. And when a space is saturated or holds the vapor to the limit, cooling will cause some of it to condense and return directly to a solid. As camphor, naphthalene, and similar moth-repellents are used in trunks and drawers, leakage allows the vapors to escape, and they are removed by the air which circulates through the room.

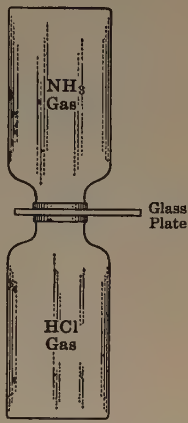


FIG. 344.—Evidence of diffusion of gases appears immediately after the glass plate is removed. Explain.

Attractive forces between molecules. The force that holds *like* molecules together is called **cohesion**; that which holds *unlike* molecules together is **adhesion.** Molecules in a drop of water, in a drop of mercury, or in a piece of iron are drawn together by cohesion, but when you mark on the blackboard it is adhesion that holds the crayon to the board. Glue is valuable because there is strong adhesive force between its molecules and those of other substances like wood and paper. There is cohesive force in liquids, but it is much weaker than in solids. There is no cohesion between molecules in gases.

Surface tension. You may have observed insects moving over the surface of water or snails in the water apparently holding onto the under surface just as if the water had a surface covering. No real covering is present, but the molecules of water in the surface layers are closer

together, making a surface film which produces a *surface tension.* This film exhibits properties of a membrane tightly stretched over the surface. Not only will the surface film hold up bodies denser than water, such as needles and razor blades, but it will keep bodies less dense down. By the force of cohesion there is an attraction between each molecule of water and all other molecules of water near it. In Fig. 345 it will be seen that below the surface a molecule, *A,* is pulled in all directions, but that molecule *B* at the surface is attracted only in three directions. Since there is no upward force there will be a resultant downward pull. This causes the crowding of the molecules at the surface which produces the surface film.

The surface tension of alcohol is less than that of water. If two small sticks are floating on water near each other and a glass rod wet

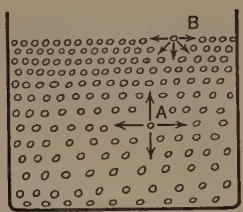


Fig. 345. — Explain how this diagram shows the cause of the surface film.

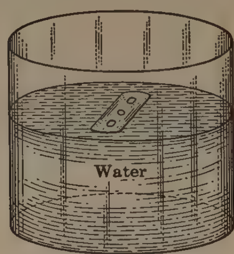


Fig. 346. — A steel razor blade supported by the surface film.

with alcohol touches the water between them, they instantly move apart as if they repelled each other. The real reason is that they were pulled apart by the surface film on the sides of the sticks away from the alcohol which weakened the film between them.

Capillarity in everyday life. When you use blotting paper, the ink passes through the tiny spaces between the fibers of the paper. If one end of a wet towel is left in a bowl of water and the other reaches to the sink outside, the water will soon be carried up the towel over the edge of the bowl and down into the sink. The carrying of liquids by fibers is an essential process in the burning of candles and oil lamps. The rising of water in soil by capillary action is of much practical value to the farmer and gardener. The height to which it will rise depends upon the size of the particles and the compactness of the soil. If the grains are coarse, the spaces between them will be large. If the grains are fine, the spaces may be large if the soil is loose but small if the particles are crowded together, as is shown in Fig. 347. There is the

same weight of soil in *B* as in *A*, but it is more compact and capillarity will be stronger.

Cultivation to loosen the soil particles and stop capillary action is practiced by agriculturists to conserve the water in the ground because, when it comes to the surface, evaporation takes place. The effect of cultivation can be demonstrated as shown in Fig. 348. Place two tubes of wet soil in bottles containing equal amounts of water. Close the mouths of the bottles around the tubes with absorbent cotton. Keep the top inch of soil in *B* loose by occasional stirring. Observe which bottle becomes dry first. The loose particles at the top of *B* check capillarity and so check loss of water by evaporation. A simple experiment for you to do at home is to cover the top of a cube of sugar with powdered (confectioner's) sugar. Dip the lower corner of the sugar into red ink or coffee. The liquid quickly rises as far as the powdered sugar, but movement through that is slow.

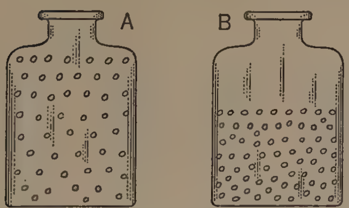


Fig. 347. — The space between the particles is less in compact soil (*B*) than in loose soil (*A*).

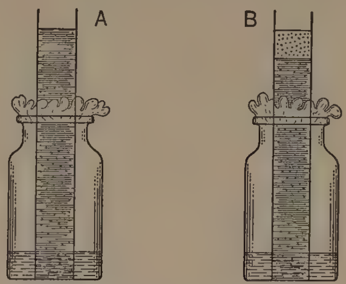


Fig. 348. — What effect will the loose particles at the top of the tube have upon loss of water in (*B*)?

Although cultivating will check movements of water through the soil, that method will hardly work with cloth. If you wish to make your tent waterproof, you must coat the fibers with something which has less adhesion for water than the cloth has. Water will not rise at the edge of a paraffin cup. If paraffin is dissolved in gasoline it can be applied to the stretched tent with a clean paint brush. Be sure there is no flame near until the gasoline has been removed by evaporation. After the gasoline has evaporated, the paraffin is left coating the fibers and well worked into the interior of the fabric. The decreased adhesive force will result in decreased capillary action and a decided increase in ability to shed water.

Capillary action. When water is poured from a glass, the walls of the glass are wet because water clings to the surface of the glass. When mercury is poured from a glass, the glass is dry because no

mercury clings to the surface of the glass. In order that some of the water molecules may pass out and leave others behind there must have been a separation between the molecules of water by overcoming the cohesive force which tends to hold them together. This was possible because of the adhesion of water molecules to the glass. We must infer that the adhesion between glass and water is greater than the cohesion between molecules of water, and that the adhesion between molecules

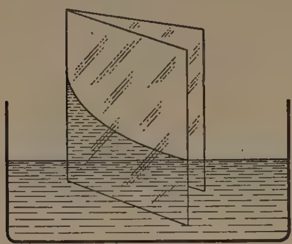


Fig. 349. — Water rises highest where the two pieces of glass are nearest together.

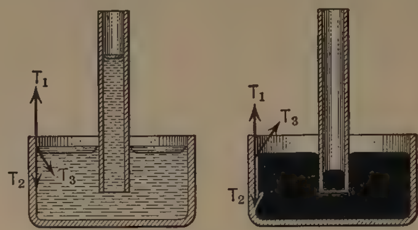


Fig. 350. — Capillarity in tubes: Water elevated and mercury depressed.

of mercury and glass is less than the cohesion in mercury. There are two types of capillary action, based upon whether or not a liquid wets a solid dipped into it. Capillarity is defined as the elevation or depression of liquids in tubes of small bore. Such tubes are sometimes called capillary tubes. Water will rise in capillary tubes to a greater height than that of the surrounding liquid, but mercury sinks in such a tube to a level below that of the mercury outside. The smaller the bore, the greater the elevation or the depression of the liquid.

The cause of capillary action. Because of the adhesive force of glass for water, the molecules of glass a little above the surface of the water pull the water up the surface of the glass to a higher level. The surface film on the water rises and lifts a column of water until the downward pull of the weight of the water balances the upward adhesive force between the glass and the water. In the case of mercury and glass, because the cohesive force in mercury is greater than the adhesive force between mercury and glass, the mercury is drawn away from the glass, and the surface film, in assuming the smallest surface area possible, pushes down the column of mercury within the tube.

Molecular motion and heat. All molecules in a body are believed to have a vibratory motion which constitutes heat energy in the body. If heat is absorbed by any material, molecules of the material increase their vibratory rate. The loss of heat by a body is accompanied by a slowing down of the molecular vibration. When an object absorbs

energy radiated to it from the sun, its molecules vibrate faster or harder, and we say that it has gained heat and has become warmer.

SUMMARY

1. All molecules vibrate. Their vibration energy is least when the substance of which they are a part is in the solid state, and greatest when it is in the gaseous state.

2. Two or more gases in contact will mix by a process called diffusion. This is due to the free motion of molecules in the gaseous state.

3. Molecules from solids and liquids may acquire enough energy to become gaseous and then mingle with molecules of the air. Examples: water vapor, camphor, moth balls, and the substances which cause the odors of flowers.

4. Some substances have a definite melting point. Others soften gradually and have no fixed temperature at which they change to a liquid.

5. Viscous liquids are those having high molecular friction which resists easy flowing.

6. Liquids are incompressible and when confined transmit external pressure undiminished to all equal areas.

7. Many properties of solids and liquids depend upon molecular action.

8. Cohesion is a force which holds like molecules together. Adhesion is a force which holds unlike molecules together.

9. The molecules at the surface of a liquid are closer together than those below the surface. This produces a surface tension or film capable of supporting light objects denser than water.

10. Capillarity is the elevation or depression of liquids in tubes of small bore. Combined action of adhesion or cohesion and surface tension causes this action.

11. Capillarity causes ink to rise in blotting paper, oil to rise in a wick and water to rise in soil above the water table.

12. The vibration of molecules in matter constitutes the heat energy that the body possesses.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. How properties of matter determine its use.
2. Capillary action in everyday life processes.
3. Practical importance of diffusion of gases.
4. Five practical uses of elasticity in the home.

CHAPTER XXV

SOLUTIONS AND OTHER DISPERSIONS

The kind of work which matter can do most effectively often depends upon its state or condition. Ice jams in northern regions sometimes remove strong bridges; running water generates powerful currents of electricity; and steam does the work of millions of men in transportation and industry. Just as water in a gaseous state has unusual force, so does any other gas. For example, confined air under right conditions may suddenly pierce tube and tire on a rapidly moving automobile, and we say the fatal accident resulted from a "blowout" in the tire. Baking powder may be kept for years in its sealed container and still be useful in cooking. But if it is exposed long to moist air or if water reaches it before it is used, its value as a leavening agent is gone. We are accustomed to see a layer of cream at the top of the bottle of cow's milk that has stood over night. Cream rises much more slowly from goat's milk, and the milk from some animals appears never to have any cream. This is not because it is not there but is due rather to the size of the particles of the fat globules.

Both the **state of matter,** whether solid, liquid, or gas, and the **size of its particles** determine in large measure some of the important properties of matter. A body of matter may be a single **pure** substance as chemically pure common salt, or a **mixture of several** substances, as the salts that would result from the evaporation of sea water. This would be **impure** salt. We may have pure distilled water or we may have spring water which is "pure" from the standpoint of health. It is safe for drinking, but contains several gases or salts in solution and would have to be classified impure by the scientist.

Dispersion medium. In the sea water the amount of dissolved material is small compared to the amount of water. In a cup of coffee the particles of sugar, of the extract of coffee, and the added cream are small in number compared to the particles of water present. In both these examples the water is the **dispersion medium.** That substance which is present in a mixture in the larger amount is called the **dispersion medium.** The substance which is present in smaller amounts is the **dispersed substance.** Air that contains a small amount of moisture is the dispersion medium and water the dispersed substance.

Water that contains a small amount of air in solution is the dispersion medium and air is the dispersed substance.

Size of particle and suspension. A cubic foot of rock has a total area of 6 square feet or 864 square inches. If this rock were to fall through the air there would be 864 square inches of surface upon which the air could act by friction or bombardment of molecules to resist its fall. This resistance would be of little avail. Cut the rock into cubic inches. The total surface is now 10,368 square inches. Now let each cubic inch be cut into cubes 1/100 inch in each dimension. This gives 1,000,000 particles from each cubic inch with a total area of 600 square inches. If all the cubic foot of rock is reduced to these small particles the total surface will be 1,036,800 square inches. It is because of this greatly increased surface area in proportion to its weight that a fine particle of matter denser than water or air will be suspended in water or in air for so long a time.

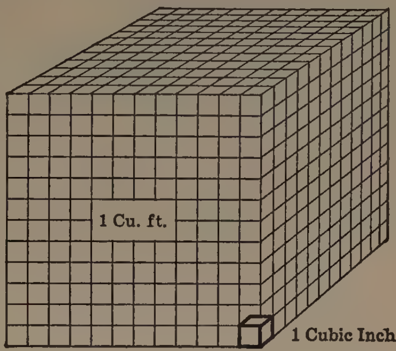


FIG. 351.—The smaller the particle, the greater its surface in proportion to its weight.

Dispersion of matter and size of particles. The size of the particles into which matter is divided often determines some of its properties. Soil with rock-dust particles large enough to be seen are carried long distances by winds. The terrific volcanic explosion of Krakatoa, a small island near Java, in 1883, sent fine dust high into the atmosphere and some of it was carried entirely around the world. Water is denser than air, but minute particles will stay suspended in air for a long time. The finer the particles in muddy water, the more slowly they settle. Particles too small to be seen individually may produce a haze in the atmosphere or turbidity in water. These small particles of dust in the air are constantly bombarded by the moving molecules of air. The enormous surface, in proportion to their weight, offers great frictional resistance to their falling. As a result the particles once put into the air will be a long time in falling. A similar resistance to settling is observed in water. A cloud of dust may be seen in the air when there is a strong wind. These large particles fall when the air is calm. In still air dust is not generally seen, but when a beam of light shines through a small opening into a darkened room, the beam becomes visible from reflection on the minute particles of dust in the air.

Classification of matter according to size of particles. Particles down to 1/250 of an inch are visible. These are macroscopic particles. Macroscopic particles may be reduced in size either by physical or chemical means until they are no longer visible. The reduction of any particle to smaller particles is called **dispersion.** On the other hand, fine particles may be united and form larger particles in the process of **condensation.**

Figure 352 shows the range of sizes of particles in various groups. Particles from 1/25,000 of an inch up will settle rather rapidly from air or water. Those in the colloidal group will remain suspended in-

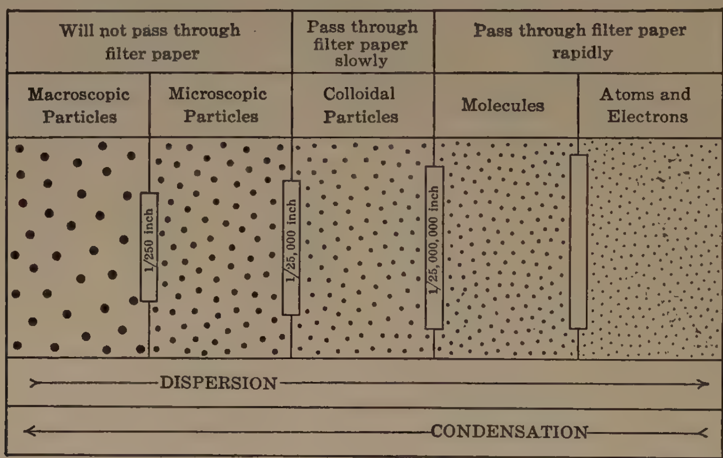


FIG. 352. — Particles of matter may be increased in size by condensation or reduced in size by dispersion.

definitely or settle very slowly. Still smaller particles form clear solutions in liquids and do not settle. Particles between 1/250 and 1/25,000 of an inch can be seen by aid of the microscope. The ultra-microscope gives evidence of particles down to 1/25,000,000 of an inch.

Microscopic particles include not only inanimate matter but likewise thousands of combinations of matter organized into living things. The colloidal range of matter makes a very important division about which we shall have more to say. The molecular condition is found in gases, liquids, true solutions, and solids. The sizes of molecules vary. Some protein molecules are more than 30,000 times as large as the hydrogen molecule. Although the size of molecules varies greatly, we may think of average molecules as having a diameter of about 1/40,000,000 to 1/50,000,000 of an inch. The smallest particles that make up matter are the components of the atom, namely, the electrons and protons.

Movement of molecules in gases. Molecules in gases show great energy of motion. They have a vibratory motion which is a measure of their heat content. They also travel in straight lines until they meet some obstacle — other molecules or the walls of the vessel in which the gas in confined. When they meet other molecules, they rebound without loss of energy and travel in a straight line until there is another collision. This action is so strong that the molecules are pushed apart and their distances from each other are so great that there is no force drawing the molecules together, but instead they seem to repel each other. A gas expands indefinitely when pressure on it is removed. Were it not for the gravity pulling downward on the air, it would wander off into space leaving the earth without an atmosphere.

Kinetic theory of gases. The Greek word *kinein* means **to move,** and it is the source of the word **kinetic.** It is assumed that all molecules in matter are in constant motion. The molecules in gases are separated by spaces which are very large compared to the size of the molecules. A cubic inch of water makes nearly a cubic foot of steam. Thus in a gas there are comparatively wide spaces through which a molecule may travel without opposition. In a gas the molecules neither attract nor repel each other. Each seems to lead an independent existence. If a cloth wet with concentrated ammonia solution is placed in one corner of the room, molecules of the ammonia gas will soon work their way through the intermolecular spaces of the air to distant points.

The continual bombardment of millions of gaseous molecules against a surface in contact with the gas results in continuous pressure on that surface. Reaction causes the molecules to bound off and continue their motion in some other direction. If a part of the gas in an enclosed space is pumped out, the remaining molecules spread out to fill the entire space. But now there are fewer molecules to bombard a given area of the walls and a reduction in the pressure results.

What causes a "blowout"? When air is pumped into an inner tube, it may increase to double its normal volume. But if the tube is confined within the tire, the same amount of air added instead of increasing its size will increase the pressure. Suppose there is a cut through one part of the tire or even a weak spot due to excessive wear and cracking of the fabric. That offers one condition needed for a serious accident. When a hot summer sun shines on a tire, heat is carried through to the molecules of air and their pressure is increased. Rapid driving also causes heating of the tires. When a rapidly moving tire suddenly strikes an obstruction on the road, increased pressure is given momentarily to the compressed air within. A combination of

these conditions may easily yield sufficient force to the compressed air within the tire so that it will blow a hole in the inner tube as the weakest spot in the tire gives way.

Solution of solids. At 15° C., 100 grams of water will dissolve 196 grams of cane sugar but only 0.17 gram of calcium hydroxide. This solution of calcium hydroxide is limewater. At the same temperature 100 grams of water will dissolve 36 grams of common table salt. We may say that salt is soluble, sugar is very soluble, and calcium hydroxide is slightly soluble in water. That the effect of heat on solubility differs greatly is shown by the following comparison of three different salts.

TABLE XXIX

COMPARATIVE SOLUBILITY OF SALTS

Salt	Grams of Salt Dissolved by 100 Grams of Water at Different Temperatures	
	At room temperature 70° F.	At boiling temperature 212° F.
Potassium nitrate	32	246
Sodium chloride	36	39.8
Calcium sulfate	0.2	0.16

The substance which dissolves in the liquid is the **solute**; the liquid is the **solvent**; and the mixture of the two is a **solution.** Heat is required to change the condition of the solid so that it goes into solution. This accounts for the lowering of temperature when some salts are dissolved in water. If, however, the solid unites chemically with the water, a rise in temperature may result. Solutions may be made in liquids other than water. Carbon tetrachloride will dissolve grease, alcohol will dissolve iodine, and gasoline will dissolve paraffin. Solution as described above is a physical process and finds many applications in the household, in manufacturing processes, and in agriculture. Except for the carbon dioxide taken directly from the air, plants get their food from solutions taken into the roots from the soil.

Saturated solutions. When a teaspoonful of salt is added to a cupful of water and stirred, all of it dissolves; but if we keep adding salt we soon find that some of it remains undissolved. There is then just as much salt separating from the solution as there is solid going into

solution. When this state of equilibrium is reached, the water has taken all the salt into solution that it is capable of dissolving at that temperature and it is said to be *saturated.* At ordinary room temperature a saturated water solution of common salt contains 32 per cent salt and 68 per cent water.

Formation of crystals. The solubility of many substances is increased by raising the temperature. If a saturated solution is prepared at a high temperature and then cooled, the solute tends to separate. By cooling a saturated solution, or by evaporation of the liquid, crystals of the solute are formed. If solutions of different salts are mixed and the solvent is slowly evaporated one salt will generally separate out before the other one does. This process of crystallization is practiced by the chemist to obtain pure chemicals. If you dissolve salt and sugar in water and evaporate slowly, crystals of salt will form and can be separated from the sugar sirup. The sap from maple trees is a very dilute sugar solution. By evaporation it becomes concentrated and makes maple sirup. If it is evaporated still further in the "sugaring-off" process, the sugar will crystallize upon cooling.

When some salts — sodium carbonate (washing soda), for example — are separated from water solution by crystallization, each molecule combines loosely with several molecules of water. This glassy-looking crystal holds the water as long as it is a crystal. By heating the crystal the water may be driven off and the salt becomes a dull powder. Sodium carbonate crystals lose the water slowly even at ordinary temperatures. Washing soda that is a dull white powder is just as efficient as the glassy crystals.

Supersaturated solutions in the home. When a hot saturated solution is cooled, the solute does not always separate. If it does not, the solution will then contain more of the solute than enough to saturate it, and it is a **supersaturated** solution. Hypo crystals can be dissolved in their own water of crystallization by applying heat. If the solution is then cooled to room temperature, it will remain a clear solution. Drop a small crystal of hypo into the cold liquid and crystallization of the entire mass will quickly follow. Sometimes jarring or shaking a supersaturated solution will start crystallization. At other times crystallization may be long delayed.

In making candy you make a supersaturated solution of sugar. When making fudge the rapid stirring is to promote the formation of many small crystals of sugar. For soft candies glucose is better because it crystallizes less easily than cane sugar. If cane sugar is used with acid like lemon juice, vinegar, or cream of tartar, it will be changed to glucose.

In cold weather you may find that the honey put away as a sirupy liquid is "candied" or that sugar crystals have separated. This is because honey is a supersaturated solution. Cooling, sometimes stirring, will start crystallization in supersaturated solutions. Concentrated sugar solutions are used in making jelly, which are little more than flavored supersaturated solutions of sugar. Sometimes in jelly kept for a long time you may find hard crystals of cane sugar which have crystallized out. When crystallized purposely from sugar sirup, these crystals are called "rock candy."

Sublimation. Some gases whether produced directly from a solid or from a liquid will upon cooling go directly back to the solid without passing through the liquid state. If a few crystals of iodine are heated in a beaker covered with an evaporating dish holding cold water, iodine crystals will soon form on the under side of the cold dish. A similar result is obtained with naphthalene, the chemical used in moth balls. This process of crystallizing from the gaseous state is called **sublimation.** It is utilized in purifying chemicals. When you buy solid iodine, the label reads "resublimed iodine." This means that the iodine has been twice purified by this process of sublimation.

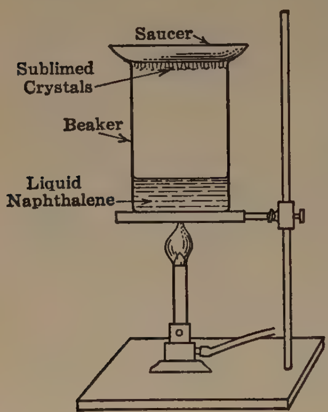


FIG. 353.—Sublimation of naphthalene. Iodine may be crystallized in the same way.

Solution of liquids. Suppose we put 10 cc. of alcohol, kerosene, glycerin, carbon tetrachloride, and ether respectively into five different test tubes. Now add 10 cc. of water to each one and shake vigorously. After the tubes have stood a short time we find that the water has separated from the kerosene and from the carbon tetrachloride apparently completely. But the alcohol and the glycerin show no separation. The water and alcohol will mix in all proportions. Either one may be said to be soluble in the other. The same may be said about water and glycerin. These liquids which are naturally soluble in all proportions are called *miscible*. Those liquids like oil and water or carbon tetrachloride and water are *immiscible* or *non-miscible*. The ether and water show separation but if carefully tested it would be found that the ether which has separated contains some water and the water contains a small amount of ether. Ether is slightly soluble in water and water is slightly soluble in ether. Gasoline and kerosene are miscible liquids. Turpentine and linseed oil are miscible, and both are

used in mixing or thinning oil paints. Rubbing alcohol is alcohol diluted with water and, of course, denatured so that it is not suitable for drinking purposes. Many hand lotions are glycerin and water with a little perfume added.

Two miscible liquids may vary in their ability to dissolve a given solid. Camphor is soluble in alcohol but insoluble in water, but water and alcohol are soluble in each other. A tincture of camphor is a solution of camphor in alcohol — whose vapors are inhaled to ease respiration in mild cases of hayfever or asthma. If water is added a little at a time to alcoholic solution of camphor, as the alcohol and water dissolve each other the camphor will be thrown out of solution as a white solid.

Solution of gases. You are familiar with the coating of bubbles that often forms on the inside walls of a glass of water left standing in a warm room or the gaseous bubbles escaping from a glass of soda water. Air in contact with water is slowly absorbed. If water is violently shaken in a bottle half full of air, some of the air is quickly dissolved. The carbonated water of the soda fountain holds much carbon dioxide in solution under pressure. When released to atmospheric pressure the gas escapes rapidly, causing the effervescence. Increase of heat decreases the solubility of a gas, and increase of pressure increases it. Gases vary greatly in solubility. Household ammonia is a dilute solution of ammonia gas in water. Cold water is able to dissolve more than 1200 times its own volume of ammonia gas. Soda water may have nearly twice its volume of carbon dioxide as it escapes under reduced pressure, but when charged under 10 atmospheres of pressure it will have ten times as much as it can hold under normal pressure. By pumping the air from a bottle nearly filled with freshly drawn water myriads of tiny air bubbles will form and escape from the water.

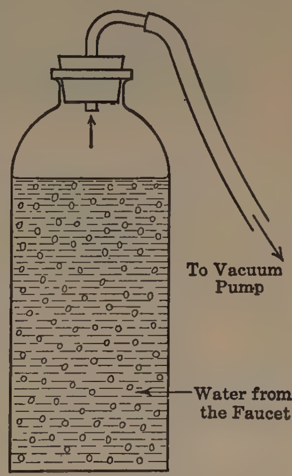


FIG. 354. — Reducing the pressure reduces the solubility of a gas.

Colloidal state. Some substances appear to dissolve in a solvent when in fact they do not make a true solution. Molecules bunched together and electrically charged may be evenly distributed in a liquid or a gas and differ from a solution chiefly in the size of the particles. These groups of molecules making up individual particles are not so large and heavy that they settle, but they are supported by the constant

Fig. 355. — The beam of light is invisible in pure water but makes a luminous path in the colloidal solution.

blows of the solvent molecules. They do not unite into larger particles and sink, since they repel each other because of like electrical charges. Their presence is shown by the diffusion of a beam of light. A true solution does not disperse and show a beam of light going through it. Bodies that produce this effect are colloids, and the mixture is a colloidal dispersion or colloidal solution.

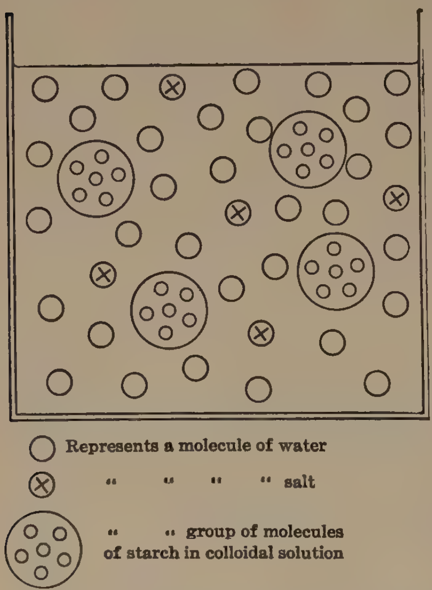


Fig. 356. — Salt and starch dispersion in water.

Table salt will dissolve in water, but in alcohol it may assume the colloidal state. Those substances which frequently assume the colloidal state, as agar-agar, gums, glue, albumin, casein, and gelatin, are called colloids; those which commonly produce true solutions, as salt, are called crystalloids. The red glass in our traffic signal lamps is made red by the addition of a small quantity of selenium to

the molten glass. The selenium assumes the colloidal state. Many gems owe their color to the presence of constituents in the colloidal state. And some scientists suggest that the blue of sky and sea may be due to colloidal dust contained in the air or in the water.

Gels. Some substances when put into the colloidal state in water, if concentration is right, "set" or form a jelly upon cooling. The preparation of glue, gelatin, and starch and the clotting of blood are familiar examples. Many fruits contain pectin, a carbohydrate having the same percentage composition as starch. Pectin is found in apples, grapes, cranberries, and the juice of citrus fruits; also in some vegetables, as carrots and beets. When pectin is boiled in the presence of fruit acids, pectic acid and salts of this acid result. These products upon cooling become gelatinous and produce jelly.

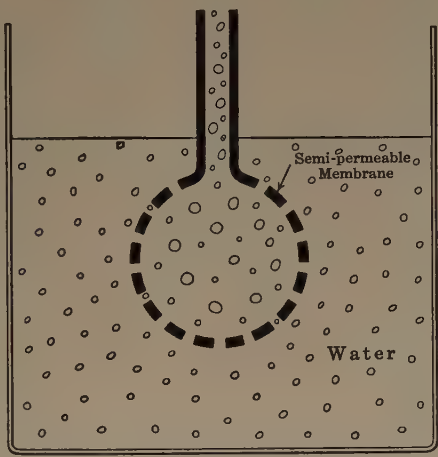


FIG. 357. — The large circles within the membrane represent sugar molecules or groups of sugar molecules; the small circles represent water molecules. Why do more water molecules pass into the space within the membrane than sugar molecules pass out?

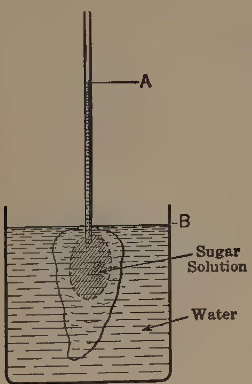


FIG. 358. — Liquid is raised from (*B*) to (*A*) by osmotic pressure through the membrane within the carrot.

Osmosis. A sugar sirup has fewer molecules of water to the cubic centimeter than pure water. The molecules of sugar are larger than the molecules of water. If a solution of sugar is enclosed in a space by a membrane of an animal, such as sausage skin, or of vegetable cells, such as parchment, and surrounded by pure water, water will pass through the membrane until the number of molecules of water per cubic centimeter is the same inside the membrane as outside. But because of the large size of the sugar molecules there will be little or no passage of sugar molecules through the membrane. The addition of water to an already filled space increases the pressure and is capable of lifting the liquid many feet above its original

level. This action is called *osmosis*, and the pressure developed is called **osmotic pressure.** Prunes, raisins, figs, peas, and beans are dried to preserve them for food. In preparing them for use they are often put in water. The skin around them is a semipermeable membrane which allows the molecules of water to pass through faster than it allows the colloidal matter inside to pass out. This develops pressure and makes the fruit or seed fill out plump. If a solution of the same substance is on both sides of the membrane, the resultant motion will be from the weaker solution to the stronger. Osmosis is of great importance in supplying plant and animal cells with food. Diffusion through the membranous walls of the root hairs of a plant by osmosis brings mineral matter from outside into the root and then may force it from cell to cell to various parts of the plant. Food in animals is liquefied and passes through membranes into blood vessels and cells to nourish them. Conditions in the soil are sometimes favorable for osmotic pressure. A layer of clay may act as the organic membrane does and carry water to a considerable height through osmosis.

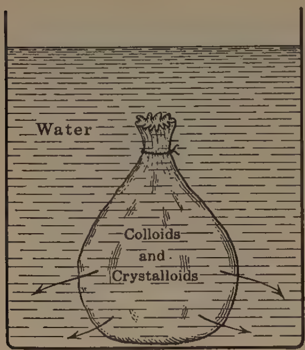


FIG. 359. — When a solution of crystalloid and a colloid is placed in a parchment bag which is then closed and immersed in water, the colloid remains in the bag but the crystalloid passes through the membrane into the water.

Dialysis. When a solution contains both colloids and crystalloids, it is possible to separate them by taking advantage of the fact that the colloidal particles are too large to pass through a membrane which will allow the crystalloid particles to go through. This process is called **dialysis.** The sugar in the juice of the beet is extracted from the cells in the beet by utilizing this process.

Emulsions and suspensions. Emulsions and suspensions are alike in that a substance is dispersed and held in a colloidal state. Ordinary paint mixed in oil consists of a pigment suspended in oil. It will settle very slowly and leave a layer of oil on top. Milk is an emulsion. The casein and butterfat are dispersed in water. The fat quickly separates, but the casein resists separation or coagulation. When kerosene oil and water are mixed and shaken vigorously, the two are thoroughly dispersed one in the other, but upon standing for a few minutes they separate. If soap is dissolved in the water first and then the three shaken as before, an emulsion is formed, and the oil remains in fine particles distributed throughout the water. This condition will continue for a

long time. Advantage is taken of this fact in making the kerosene emulsion spray to kill insects on plants and in sprinkling oil on streets to lay the dust. Some inks are true solutions; in others the material which gives the ink its color is held in suspension by a colloidal substance, or an emulsion is produced.

In milk the butterfat is held by the casein as the emulsifying agent. In mayonnaise the yolk of egg is used as the emulsifying agent. Many vaseline ointments, salves, and other soft greases or creams are typical emulsions. Under high pressure, milk can be squeezed through minute orifices, so reducing the size of the cream or fat globules that they will remain uniformly distributed. The fat globules are changed from the emulsion state into the colloidal state. When you buy milk prepared in this way, cream will not rise in the time that it is ordinarily kept in the home. Milk so treated is said to be homogenized.

Coagulation. If anything happens to remove the electrical charge of the colloidal particles they will then join together into larger particles and separate as a gelatinous precipitate or gelatin. Acid or rennin added to milk causes curdling. Gelatin, glue, and fruit juices containing the coagulating colloid pectin will, when concentrated to the right degree, " set " upon cooling and make a firm jelly. Soap is a partly dried gelatin. The emulsion on a photographic film is a completely dried gelatin. Gum arabic is added to some black inks as a protecting colloid to prevent coagulation and separation of the black coloring. Clotting of blood and the cooking of eggs are colloidal processes.

Adsorption. When one body is capable of holding to its surfaces a large quantity of another substance, as when charcoal takes up a gas in a gas mask, the action is called **adsorption.** Whether it is a mechanical adhesion or chemical action with surface molecules is of little consequence. The usefulness of gas masks depends in large measure upon it. One gram of charcoal may be divided so that it will have over 100,000,000 square millimeters of surface area. In the coagulation process of purifying water, in which aluminum hydroxide is precipitated in water containing finely divided suspended matter, the hydroxide adsorbs the suspended particles. As these settle the water is purified.

It is a process of adsorption by which crude sugar sirup has its color removed by filtering through boneblack and the yellow coloring is removed from cottonseed oil. Dyeing of cloth is an application of adsorption in which there is precipitation of colloids. In dry cleaning the use of soap aids in taking out dirt particles by adsorption between dirt and soap particles.

Some drugs used in liquid medicines may be adsorbed by colloids and held in water in which they are insoluble.

Properties of solutions. Ocean water does not freeze at the same temperature as lake water. This is because of the salts in it. Solutions have a lower freezing and a higher boiling temperature than the solvent. Colloids have little effect on freezing and boiling points. You can get a higher cooking temperature in a double boiler by using a strong salt solution in the outside vessel.

Since substances are separated into individual molecules and even some molecules are subdivided in a true solution, chemical action is aided. In baking powder, two chemical substances with possibly an inactive substance like starch are thoroughly mixed and yet if kept dry they do not react upon each other. If, however, they are dissolved in water they immediately react and set carbon dioxide free. The chemist makes use of solution in many of his tests. The manufacturer uses solution in making many chemical products. Solution is utilized in many household processes as cleaning and cooking. Biological processes in animals and plants depend upon the action of colloids.

SUMMARY

1. In a mixture of two substances in which one is evenly distributed throughout the other, the one present in larger amount is the dispersion medium and the one present in smaller amount is the dispersed substance.

2. Particles of matter are reduced in size by dispersion and increased in size by condensation.

3. According to the kinetic theory, molecules of gases move in straight lines across intermolecular spaces. When they meet other molecules they rebound without loss of energy.

4. The repeated impacts of gaseous molecules upon a surface results in continuous pressure.

5. Water-soluble solids when placed in water separate into molecules which spread out or diffuse throughout the liquid and produce a solution. The substance dissolved is the solute, and the liquid the solvent. When the solvent holds all the solute it is capable of holding at a given temperature, the solution is saturated. Solution is generally attended by a fall in temperature.

6. Evaporation of the solvent of a solid solute leaves the solute in the solid state and often in crystal form.

7. Liquids and gases may also be dissolved in appropriate liquid solvents.

8. When a hot saturated solution is cooled and none of the solute

separates, it is in a supersaturated condition. It has more of the solute in solution than the solvent can dissolve under normal conditions.

9. Condensation of a gas directly to a solid without going through the liquid state is called sublimation.

10. Miscible liquids are those that will dissolve each in the other in any proportion.

11. Heat reduces but pressure increases the solubility of gases in water.

12. The solution of salt in water lowers its freezing point and raises its boiling point. Colloids have very little effect upon freezing and boiling temperatures.

13. Substances like salt which separate into molecules and make true solutions are called crystalloids. Substances like gelatin whose fine particles made up of groups of molecules remain suspended in a liquid are colloids.

14. Some colloids which are in solution when hot, set and form a jelly upon cooling, as glue, gelatin, and compounds in the blood which cause it to clot.

15. Pectin, a constituent of some fruits, when boiled in the presence of fruit acid yields pectic acid and salts which produce a jelly upon cooling.

16. When colloidal particles lose their electric charges, they unite to form larger particles in a process of coagulation.

17. Emulsions and suspensions resemble colloidal solutions, but the particles held in suspension are larger than those held in the colloidal state.

18. Osmosis is a process of diffusion through a porous membrane. When a solution of a substance, sugar for example, is on one side of a certain animal or vegetable membrane and water is on the other, water molecules pass through the membrane faster than sugar molecules. As a result, the level of the liquid on the sugar side is raised and the pressure is increased.

19. Crystalloids and colloids can be separated by dialysis, which is diffusion through a porous membrane.

20. Absorption is simple penetration of molecules to the interior of a solid. Adsorption not only involves absorption but in addition molecular force that attracts and holds to a surface molecules of a different kind.

21. Solution is an aid to chemical action.

22. Crystallization is a purifying process.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Industrial uses of colloids.
2. Crystallization as a purifying process.
3. Jelly making.
4. Making crystals.
5. Pressure from gases.
6. Uses of absorption and adsorption.
7. Coagulation of viscose in making rayon.
8. Industrial applications of homogenation.

CHAPTER XXVI

SOUND IN THE HOME

What is sound? If we bring a pith ball, held by a thread, to the prong of a sounding tuning fork, the ball will be violently forced away. If we touch the surface of water with the end of the sounding prong, a spray of water will result. If a wire is attached to one prong of a fork, and, when the fork is sounded, we draw a smoked glass under it, with the wire resting lightly on the smoked surface, a wavy line is produced. None of these results occur if the tests are made when the fork is quiet. These experiments show that the fork, when producing sound, is vibrating. The prongs move back and forth with great rapidity. By using a pendulum to mark off a known interval of time on the smoked glass at the same time that the fork is making a record of its vibrations, it is possible to determine the number of vibrations per second, or the vibration **frequency.**

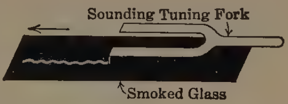


FIG. 360. — Proof that a sounding tuning fork is vibrating.

It is said that a frequency of 16 vibrations per second will produce the sensation of sound in some persons, while in others vibrations lower than 30 are not heard as sound. From these lower limits, vibrations up to 20,000 or more per second are heard as sound by most people. The $7\frac{1}{3}$-octave piano has a range from $27\frac{1}{2}$ to 4600 vibrations.

Sound is that form of vibratory motion which is capable of affecting our sense of hearing.

How sound travels. Experiment shows that sound will not travel in a vacuum. Matter is necessary to transmit the sound wave. When a body is sounding in air, we may be reasonably sure that the air is carrying the sound. We also know that sound travels in every direction from its source; otherwise it could not be heard in all directions. The wave must therefore be spherical in form.

To understand just what this wave is, let us consider a portion of the entire wave, just that portion in the air between a sounding tuning fork and the ear. The air, as we know, is composed of molecules separated by spaces. During vibration, the fork moves from its position of rest *R*, Fig. 361, to the right *A*, back to *R*, continuing to the left to *B*, then back to *R* and to *A*, and so on. When the fork moves from either *B* or

R to *A*, it strikes the molecules of air a blow which pushes them forward, crowding them nearer together than they were. This condensation of air molecules continues as a *wave motion*. The molecules of air move forward a short distance, and give their energy to other molecules, which in turn pass it on to still others. Thus there is no stream of air molecules as a wind passing from the fork to the ear, but only a wave. When the fork goes back from *A* to *B*, it leaves a space behind it with fewer molecules than are in normal air. This rarefied space always follows a condensation. Thus a complete *sound wave is made up of a condensation and a rarefaction.* A body producing a sound due to 256 vibrations per second will send out 256 condensations and rarefactions every second. These are transmitted by the air.

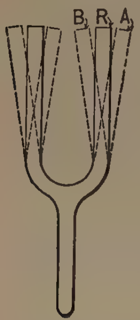


Fig. 361.— Motion of the prongs of a sounding tuning fork.

Sound will travel through solids and liquids even better than through gases. If you hold your ear near a steel rail and someone a distance away strikes the rail a hard blow, you will hear the sound twice, first through the rail and a little later through the air. At the temperature of freezing water, sound travels 1090 feet per second, but in water it travels four times as fast as this, and in steel fourteen times as fast. Sound travels faster in warm air than in cold air. Sound waves may be reflected, and when the reflecting surface is at least 60 feet away, the reflected sound may be heard as an **echo.**

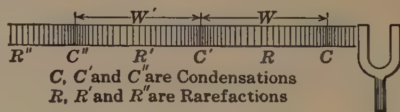


Fig. 362.—Sound waves. *W* represents the wave length.

Loudness of sound. Three factors determine the loudness of a sound in air. We all know that *distance* is one factor. Since sound travels in spherical waves which are ever growing larger, the energy is covering a larger and larger space and so must be weaker in any one place. The surface of a tuning fork is small, and for that reason it is unable to move a large body of air. If, however, the end of the fork handle is pressed firmly against the table top, it forces the *larger surface* into vibration, with the result that a larger air surface is affected and a louder sound produced. The third factor is the energy of vibration, or *amplitude*. When the prongs of the fork are plucked lightly, a

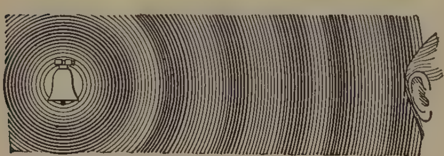


Fig. 363.—Sound travels in spherical waves in a single medium of uniform density.

soft sound is heard; but when struck sharply so that they vibrate through a greater space, they produce a much louder sound.

Sympathetic vibrations. It frequently happens that, when a certain note on the piano is struck, some object in the room will be set into vibration and produce sound. The sounding piano wire will also set a violin string of the same pitch (same number of vibrations) into vibration if it is near. This vibration of one body, caused by the vibration of a neighboring body of the same pitch, is called *sympathetic vibration.* It may be demonstrated by having two mounted tuning forks of the same pitch near each other. When one of them is set into vibration and quickly stopped, the second fork will be found to be giving out sound.

Interference and reinforcement. Sound waves may unite so that one neutralizes the effect of the other, or so as to increase the sound, according to the phases of the waves which come together. If two waves of the same frequency come together in opposite phase, that is, if the condensation of one meets the rarefaction of the other, both being

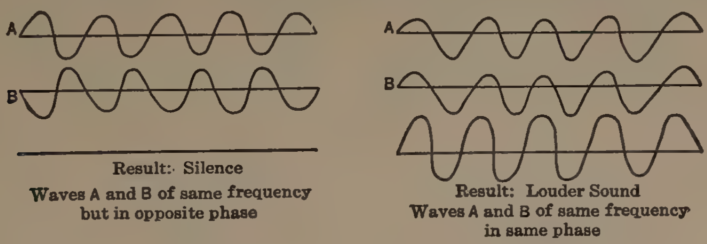


FIG. 364. — Interference and reinforcement of sound waves.

of the same amplitude, silence will result, as illustrated in Fig. 364. This is called *interference.* But if these two waves combine like phases, that is, if the condensation of one unites with the condensation of the other and their rarefactions combine also, then the loudness of the sound will be increased, or we may say there is *reinforcement* of sound, Fig. 364. If two sound waves differ slightly in frequency, some of the condensations of one will unite with the condensations of the other and reinforce the sound, but other condensations of one will unite with rarefactions of the other and reduce, if they do not destroy, the sound. As a result there will be periodic increases and decreases in sound, known as **beats.**

Two notes on the piano, whose vibration rates differ from 10 to 40, will, if sounded together, produce unpleasant discord because of the beats which result. When the number of beats is as high as 60 the discord ceases, because the beats are not distinguishable as individual sounds, but rather as one harmonious sound.

Music. Musical sounds produce a pleasing effect upon the ear; noise is a combination of sounds which is unpleasant to the ear. To illustrate this, try the following experiment: A metal disc having two rows of holes, one equally spaced, the other irregularly spaced, is rotated rapidly and a current of air blown into the holes. Each puff of air through a hole gives the same effect on the air which it strikes as a vibrating body; hence sound results, as it does in the familiar siren whistles. It is found that when these impulses are regular, a musical sound is produced, but when the impulses are irregular, noise results.

Musical sounds may vary in their number of vibrations, or **pitch.** Sounds resulting from few vibrations per second have a low pitch, and those having many vibrations have a high pitch. Not all sound which is rhythmic and has a definite pitch is musical to all people. For example, the monotonous tom-tom and the cries that accompany the Indian war dance are not music to us, though they may be to the Indian.

Harmony. When sounds due to frequencies which bear a simple ratio to each other act together, the result is *harmony*. For example, if three bodies sound together, and one of them gives 256 vibrations per second, the second 320, and the third 384, harmony will result, for their vibration ratio is simple, being 4 : 5 : 6. Any combination of three notes having this same ratio is known as a *major triad* or *major chord*.

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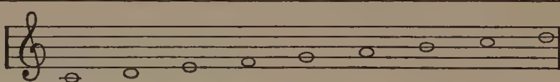


Name	do	re	mi	fa	sol	la	ti.	dó	ré
Vibration ratio	1	9/8	5/4	4/3	3/2	5/3	15/8	2	18/8
Vibration frequency (Physical)	256	288	320	341.3	384	426.6	480	512	576
Letter	C	D	E	F	G	A	B	C′	D′
Three triads	4		5		6				
					4		5		6
				4		5		6	

Fig. 365. — The musical scale.

Diatonic scale. If we take the major triad suggested and then with the note of 384 vibrations as the starting point initiate a second triad, we shall have, for the second triad, a vibration ratio of 384 : 480 : 576. A third triad which ends with the octave above 256 or 512 will give $341\frac{1}{3}$: $426\frac{2}{3}$: 512. By arranging these frequencies in numerical order we have the *major diatonic scale*.

Middle C of the piano scale is considered by physicists to be 256 vibrations, but in music it is usually a different number. In the **international pitch** middle C is 261, in **concert pitch** it is 274, vibrations. The ratios for the different notes, however, are the same as suggested above. Intermediate tones are produced by adding notes between C and D, D and E, F and G, G and A, and A and B. These are the sharps and flats, the black keys on the keyboard. The octave contains twelve notes, with a range as from middle C to the C above.

Perfect scale of Key of C	256.0	288.0	320.0	341.3	384.0	426.6	480.0	512.0
Tempered " " " " "	256.0	287.3	322.5	341.7	383.6	430.5	483.3	512.0
Tempered international pitch for piano. White notes	258.7	290.1	325.9	345.3	387.6	435	488.3	517.4
Black notes	274.1	307.6		365.8	410.6	460.9		
White and Black Piano Keys								

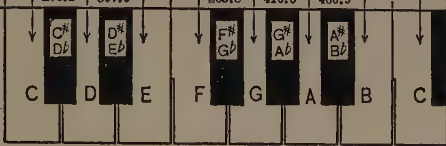


Fig. 366. — The tempered scale.

Tempered scale. If the scale on the piano were made perfect for the key of C, it could not be used for the other keys. By sacrificing the perfect intervals for one key and making the intervals between any two adjacent tones the same throughout the entire keyboard, it is possible to use music written in any key. The imperfection in musical quality introduced by this device is small, and is not observed by the ordinary person.

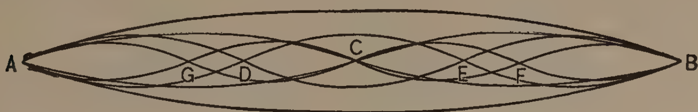


Fig. 367. — The wire *AB* sounds its fundamental when vibrating its full length; its first overtone when its halves *AC* and *CB* vibrate; its second overtone when thirds, *AD, DE, EB* vibrate; and its third overtone when it vibrates in quarters, *AG, GC, CF,* and *FB*.

Vibration of strings. The sound derived from vibrating strings varies in quality and pitch. The material largely determines the quality, but pitch depends upon *thickness, length,* and *tension.* The bass strings of the piano are coarse and long; the high-pitch strings are fine and short. The tension on the strings may be changed. The process of tuning a piano consists in changing the tension of each wire

until it gives a note in unison with some standard. The pitch of a string is doubled by having its length halved. A string may vibrate in parts while it is vibrating as a whole. The tone produced by vibrating as a whole is the **fundamental tone.** **Overtones** result from the vibration of parts of the string.

The piano. In the back of the upright piano, or under the lid of the grand piano, are found the piano frame and *sounding board.* Here the wires are strung. Each key of the keyboard controls a felt-covered *hammer.* When the key is pressed down quickly, the hammer, by means of connecting levers, strikes a blow on the wire. When the key is released the felt comes in contact with the wire and stops its vibration. The hammers and dampers are also under control of the foot pedals. The loud pedal removes the dampers, thus allowing the strings to vibrate freely. The soft pedal shortens the stroke of the hammers, with the result that a gentler blow is struck. Since repeated blows and changes of temperature tend to loosen the wires, frequent tuning is necessary. The piano should be subjected to as little extreme heat or cold and as little rough usage as possible. If a string is struck at a point one-fifth of its length from one end, it will give out a maximum number of overtones. The hammer is so placed in the piano as to produce this pleasing effect. In an upright piano the sounding board at the back of the wires throws the sound forward, but in the grand piano, with its sounding board horizontally beneath the wires, the cover must be raised and supported at an angle of about 45° to reflect the sound when full volume is desired.

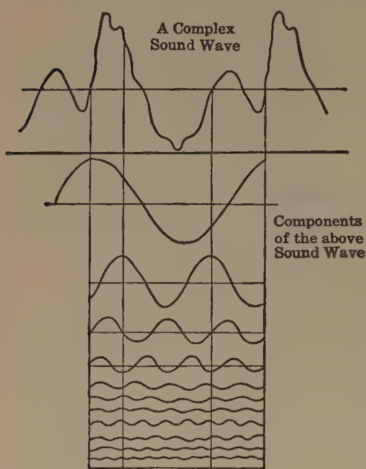


FIG. 368. — The richness of quality of the complex sound is due to the many overtones which blend with the fundamental.

The piano player. The motive power of the piano player is air. A bellows, which may be operated by foot pedals or by electric motors, produces a vacuum against which atmospheric pressure can operate the keys. A perforated music roll passes over the *tracker bar,* which has an opening in it for every note on the piano. From each opening a tube passes to a pouch which has a pinhole connection to the *air chest.* Each air chest is connected to an *air finger* — a small bellows — whose openings are controlled by the valve. Pedaling sucks the air from the air

chest and tubes, so that a partial vacuum always exists in the air chest. When a perforation in the music roll passes over an opening in the tracker bar, air from the room passes through the tube to the pouch and pushes the valve, with the result that the valve discs close the passage from the air finger to the outside air but open the passage to the air chest. As the air in the air finger rushes into the air chest, atmospheric pressure on the outside causes it to collapse. In collapsing, the top part acts as a lever, causing the hammer to strike the piano strings just as striking the piano key with the finger would do. When the hole in the tracker bar is closed by the moving roll, the valve is pushed back by atmospheric pressure, and air enters the air finger, making it ready for the next striking of that note.

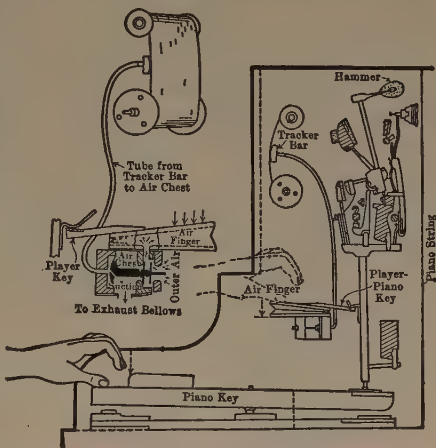


Fig. 369. — Mechanism of the piano and of player attachment.

Other stringed instruments. In the piano and harp, the length of the string is fixed, and but one note can be produced upon it. In most of our stringed instruments, however, instead of a hundred or more strings, there are but a few: four on the violin, mandolin, and banjo, and six on the guitar. By shortening these strings it is possible to produce ten to twenty different notes from each of them. The shortening is done by pressing the string against the neck of the instrument with the fingers of the left hand.

Fig. 370. — Stringed instruments.

The sound is greatly multiplied in all these instruments by forced vibrations and resonance of the sounding box and surfaces. The strings in these instruments are not so well protected as those of the piano, and so need tuning more frequently.

Wind instruments. Sounds in wind instruments are produced in three different ways: by *vibrating air columns;* by *vibrating reeds;* by *lip vibration.* The quality of the sound is also greatly modified by the form of the instrument. In the ordinary whistle and the organ pipe, a column of air is set into vibration by forcing air across a narrow opening at one end of the pipe. In the breath harp, or *harmonica,* the accordion, and the house organ, many thin metal reeds are so placed that a strong current of air will set them into vibration. The reeds are of different lengths. The short ones have a high and the long ones a low pitch. The clarinet and saxophone have a vibrating reed in the mouthpiece. In the horn, bugle, and trombone, the vibrating lips of the player force the air column within the instrument to vibrate.

Fig. 371. — Reed instruments.

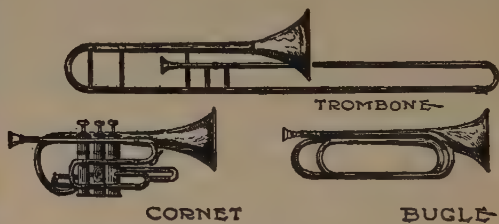


Fig. 372. — Lip vibration instruments.

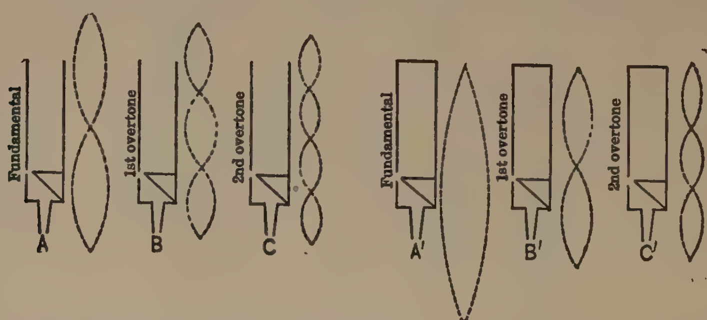


Fig. 373. — Overtones of organ pipe. *A, B,* and *C* are open. *A′, B′,* and *C′* are closed. The dotted lines represent the sound waves produced in each.

Vibrating air columns. The length of an organ pipe determines the length of the vibrating air column and in this way determines the pitch

of the sound. The shorter the air column, the higher the pitch, other conditions being unchanged. When the end of the organ pipe is open, the tone is an octave higher than when it is closed. Such instruments as the clarinet and flute have one fixed pipe. Many holes in this pipe are closed by keys, and may be opened by pressure of the fingers. When any hole is opened, the resulting note is that which would be produced if the pipe were cut off at that point. In the trombone, a sliding extension makes it possible to change the length of the air column. Columns of air may vibrate in segments, just as strings do; thus many overtones may be produced with the fundamental of a vibrating air column.

How we speak. In our vocal cords and other speech accessories, we have a mechanism capable of the most varied sounds, from harsh noise to the softest music. Few people train themselves in right voice usage, or are even aware of the possibilities which lie dormant in the human voice. Situated in the throat where "Adam's apple" is found, is the *larynx.* Within the larynx is the *voice box.* In this are two *membranous cords* which are attached to the side walls and partly close the opening, leaving a narrow slit across the middle. By muscular action the slit between the two edges of the cords may be changed. As air is forced through this slit the cords are set into sound-producing vibration.

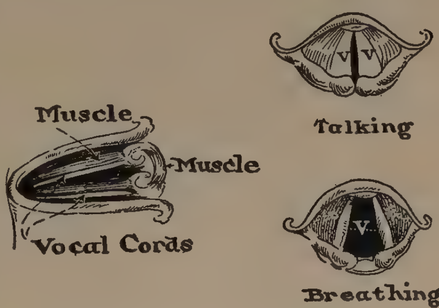


Fig. 374. — The vocal cords.

The voice. The human voice, which is the result of the action just described, may be changed at will. The cords may be put under greater or less tension. They may be shortened or lengthened. This variation chiefly affects the pitch of the sound. The mouth and nose cavities act as resonators, and the position of the tongue also modifies the quality of the sound. In our ordinary conversation, we are unconscious of the pitch or quality of our voices, because the act of speaking has become reflex through long custom. The vocal cords, as a rule, are larger in a man than in a woman. This accounts for the lower pitch in the voices of most men. The character of the vocal cords determines whether their possessor will make a bass, tenor, or soprano singer.

Children, particularly boys, undergo "a change of voice," during which the voice changes from one of high pitch to one of low pitch. This is due to the rapid growth of the vocal cords which occurs at that time.

Range of musical instruments. The piano has a much longer range than any other musical instrument, or than the human voice. These ranges vary greatly in their starting and ending points. The violin has a range of four octaves. The range of the human voice is only about two octaves, but, by training, it may be increased a little. A much narrower range is used in ordinary conversation.

The quality by which one sound is distinguished from another of the same pitch is largely due to the mingling of harmonics. The range of possible harmonics extends from the vibration rate of the sound produced through all wire vibration rates. Radio broadcasting transmitters have a range covering all that of the piano. A good radio re-

RANGE OF PIANO SCALE

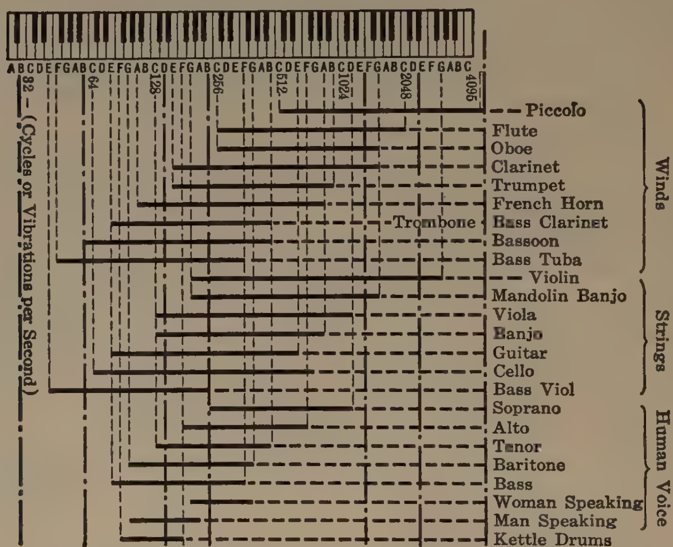


Fig. 375. — Tonal range of music-producing devices. ——— Range of fundamental notes. – – – – – – Range of harmonics.

ceiver and the telephone have a range from about 50 vibrations up. The midget radio receivers have a shorter range — about 250 to 2500 vibrations.

How we hear. When a sound wave comes to the ear, it enters the external ear passage and continues until it meets the membrane of the eardrum, separating the internal and external air passages of the ear. The air pressure on both sides of the membrane is equalized by an open air passage (Eustachian tube) which connects the middle ear to the mouth. Three small bones in the middle ear communicate the vibrations received by the membrane to the fluids contained in the cochlea

of the inner ear. In this chamber are 3000 minute fibers, each of which is capable of vibrating at a certain frequency. Disturbances in these fibers, in which are the ends of the auditory nerve, are transmitted to the brain as nerve impulses, and the sensation of hearing is the result.

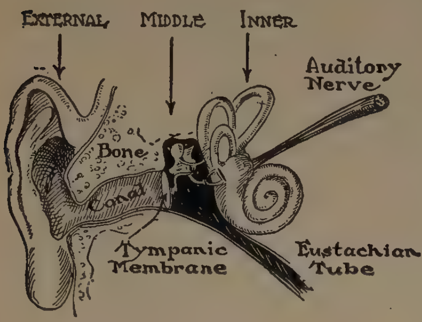


FIG. 376. — Section of the ear.

Just as there are ether vibrations too slow and others too rapid to affect our sight, so there are vibrations in matter with frequency too low, and others with frequency too high, to affect our hearing. The range of the human ear is about ten octaves.

The phonograph. The phonograph is one of Thomas A. Edison's inventions. The production of a "record," until a comparatively recent time, was by an entirely mechanical process which is as follows. A person talks, sings, or plays into a horn which has a sensitive diaphragm at the small end. The diaphragm vibrates to correspond to the sounds produced. This vibratory motion is communicated through a needle to a cylinder or plate of wax, which slowly turns under the needle as the sound is being produced. The needle makes a groove in the wax. This groove is not smooth but wavy. When the vibrating diaphragm is horizontal, the irregularities rise and fall, giving a groove known as the *hill-and-dale*. When the vibrating diaphragm is vertical the irregularities are sidewise and produce a *lateral* groove. In another method the needle of the vertical diaphragm may trace a lateral line on a greased metal disc. By acid etching and electrotyping, a master record is made, from which hundreds of copies can be made on composition materials held in contact with it under pressure. After this record is made, if the needle retraces its path from the beginning, it will be moved exactly as it was when the record was being made; but this time, as it follows the contour of the groove, it produces vibrations in the diaphragm. The diaphragm is thus made

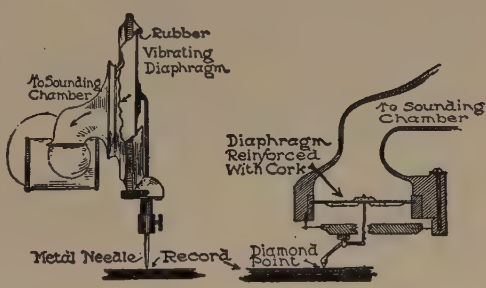


FIG. 377. — The phonograph.

to vibrate in just the same manner as it did at first, but now it creates sound waves in the air which may be communicated to the ear. The diaphragm in the reproducer must be in a vertical position for the lateral records and in a horizontal position for the hill-and-dale records. (See p. 420 for electrical method.)

SUMMARY

1. Sound is the result of vibration, in matter, of frequencies which are detected by the auditory nerves.

2. Sound travels in waves through matter. Sound waves consist of alternate condensations and rarefactions. The denser the matter, the faster the sound waves travel in it. An echo is a reflected sound which is distinct from the original.

3. The greater the amplitude of vibration, the louder the sound. Loudness decreases with the distance from the source. Forced vibration in a larger surface increases the loudness.

4. A vibrating body is able to set another body of the same frequency into vibration. Vibrations caused in this manner are called sympathetic.

5. Two waves may unite in opposite phase to neutralize each other, or in like phase to reinforce the sound. Beats result when two bodies of nearly the same vibration numbers are sounding together.

6. Musical sounds vary in pitch, which depends upon the frequencies.

7. Musical sounds are those which are pleasing to the ear; noise is an unpleasant combination of sounds.

8. A major chord consists of any three notes having the ratio 4 : 5 : 6. A series of these chords gives the notes used in the diatonic scale. By varying the vibration rate of each note in this scale a small amount, in order to make the intervals between two adjacent notes equal, the tempered scale is produced. Music in any key can be played on the tempered scale.

9. The pitch of a vibrating string depends upon the thickness, length, and tension. Shortening a string raises the pitch. When the whole string vibrates it produces its fundamental note. When it vibrates in parts it produces overtones.

10. The piano has many wires of varying sizes. Striking a key causes a hammer to strike a particular wire, at such a point as to produce the maximum number of overtones.

11. The piano player consists of a bellows for producing a vacuum in an " air finger," so that atmospheric pressure may push the key down

and make the hammer strike the string. Each key, through an air finger, is under the control of the stops and openings in a sheet of paper (music roll) which passes over a tracker bar connected by pipes to the vacuum chamber.

12. Many of our stringed instruments have only a few strings, but, by fingering, each string is made to produce many different notes.

13. There are three types of wind instruments, producing sound by three methods, viz.: vibrating air columns, as in the organ pipe and whistle; vibrating reeds, as in the harmonica and house organ; and lip vibrations, as in the cornet and bugle.

14. A phonograph record is made by producing the sound before a diaphragm, whose vibrations are recorded in soft wax from which duplicate records can be made. A finished record, placed under the needle attached to another diaphragm, causes vibration in the diaphragm and thus reproduces the original sound.

15. The human voice results from the vibration of vocal cords attached to the walls of the voice box in the larynx.

16. The piano has a range of seven octaves; the violin, four; and the human voice, about two.

17. When a sound wave meets the ear membrane, it makes it vibrate. This vibration is carried through the middle ear, by three small bones, to the inner ear, which transmits the sensation to the brain.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Measuring distance by means of sound.
2. Major and minor chords.
3. A study of pitch from experiments upon some stringed instrument.
4. Prevention of echo in large auditoriums.
5. Measurement of loudness of sound.

CHAPTER XXVII

FORMS OF RADIANT ENERGY

Radiation wave lengths. The radiations we are most familiar with are those of light and heat. We can detect light radiations by sight and by photographic processes. Heat radiations may be detected by the sense of feeling when the object is sending out radiations warmer than the human body. Bodies we call "cold" also radiate heat. A cake of ice at 0° C. will radiate heat to a near-by object whose temperature is —40° C. Large amounts of heat are radiated only by bodies which are also hot enough to radiate light. When a body just becomes visible at a temperature of 500° C. it is radiating much heat and a little light. The radiation is therefore for the most part infra-red rays. Dull red comes at 700° C., orange at 1100° C., and white heat at 1300 to 1500° C. At these higher temperatures more heat as well as more light radiations occur.

Radiant energy also includes other radiations, some whose waves are longer than those of heat and others shorter than those of light. If we consider the ether as the medium of transfer of these radiations, we have a vast range from the long electrical wave to the short cosmic rays. The long waves are measured in meters or centimeters, and the short ones in Ångströms. The Ångström is 1/100,000,000 of a centimeter (10^{-8}). The properties of different radiations are indicated in Table XXX. In this table the separation of one group of waves from another is schematic rather than exact. In fact, there is no exact line separating one group from another. All waves in the ether are **electromagnetic waves.** Subdivisions of this band, roughly according to wave lengths, give these groups of ether waves: long electric (60-cycle A.C.), radio, short electric, heat (or infra-red), light, ultraviolet, X-ray, gamma ray, and cosmic ray. The short electric waves and the infra-red waves overlap each other. There is overlapping between infra-red and visible light, and between visible light and ultraviolet light because the range of visible rays varies in different observers. Rays which appear as visible light to one person may be invisible infra-red or ultraviolet rays to another. The overlapping between gamma rays and X-rays is very extensive. Most of the gamma rays are identical with X-rays. The distinction is rather in their source than in their prop-

TABLE XXX

RADIATION WAVES

Type of Wave Radiation	Origin	Wave Lengths	Characteristic Properties	Vibrations per Second
Cosmic ray	Union of electrons and protons to form atoms (?)	0.0002 Å 0.07 Å	High penetrating power. Build up atoms. (?)	150×10^{20} 430×10^{17}
Gamma ray	Disintegrations of atoms	0.6 Å	Ionize gas. Chemically active.	500×10^{16}
X-ray	Hard X-rays Cathode-ray impact Soft X-rays	140 Å	Penetrate most metals except lead. Ionize gases. Chemically active.	214×10^{14}
Ultraviolet ray	Vibrating electrons	3900 Å	Do not penetrate glass very well. Penetrate quartz. Chemically active. Are refracted.	103×10^{13}
Light	Vibrating electrons	8000 Å	Chemically active. Act on eye. Visibility.	385×10^{12}
Infra-red (heat)	Vibrating atoms and molecules	0.03 cm.	Produce heat in matter. Are refracted like light.	100×10^{10}
Short electric	Oscillating electric charge	0.748 m.	Penetrate matter. Capable of being detected by electrical resonance. (401,000 kilocycles.)	401×10^{6}
Radio	Oscillating electric charge	30,000 m.	Penetrate matter. Capable of being detected by electrical resonance. (10 kilocycles.)	100×10^{2}

erties. If produced by a radioactive substance they are called gamma rays, but if from a high-vacuum tube under high electrical pressure discharge they are X-rays. High-vacuum tubes are now in use which

give the gamma-ray equivalent to radiation from several million dollars' worth of radium.

Signal lights. Why are red and green used for signal lights rather than blue and violet? Blue and violet rays are due to very short ether waves, whereas red and green are due to long ether waves. Long ether waves pass through obstructions such as particles of dust and water vapor in the air with less loss from absorption than the short waves. As a result, red rays can be seen through mist or fog for a greater distance than blue rays. A few years ago, the Germans replaced a 10,000-candlepower oil lamp in a lighthouse by a 1,000,000-candlepower arc lamp. The oil lamp is rich in long wave lengths near the red and yellow part of the spectrum; the arc lamp is rich in short wave lengths near the blue and violet part of the spectrum. In clear weather the new light was visible for a much greater distance than the oil lamp, but in foggy weather its visible rays fell far short of those from the oil lamp. You can see this difference in penetrating power if you can find an electric advertising sign with changing red and blue lights. You will observe that in a fog you can see the red from a greater distance than the blue. The finer the particles of moisture in the air the greater the penetration of the red rays. In a dense fog due to coarse particles the red rays have small advantage over the other rays since neither can penetrate very far. The neon lamp gives a red colored light at low cost. A 6000-candlepower neon light is visible 45 miles away.

Infra-red rays. One use suggested for infra-red rays is the sending of messages. The visible light rays can be filtered from the radiations given out by an arc light by glass containing oxides of iron and manganese which is transparent to the longer infra-red rays. These rays may be sent in a beam just as a searchlight sends a beam of light. There are several devices which will detect these invisible rays many miles away. One employs a phosphorescent substance. Infra-red rays falling upon a phosphorescent substance cause the phosphorescence to disappear instantly. Signals in Morse code may be made by interrupting the beam of infra-red rays. The beam is received in a concave mirror focused on a traveling belt coated with the phosphorescent substance that has previously passed under ultraviolet rays which cause it to continue to glow when it is in the dark. Each impact of infra-red rays upon it makes a dark space on the glowing line of phosphorescent material. Infra-red signals may be transmitted by this method for distances over 20 miles.

By means of specially coated plates photographs can be taken in the dark, the chemicals used being sensitive to infra-red rays. The photograph shown in Fig. 378 was taken on an infra-red-sensitive plate.

Infra-red radiation was directed to the ceiling and reflected to all parts of the room, but as far as sight is concerned, the men were all the time in absolute darkness. The plate was exposed 1 second at *F* 3.5. The plate was then developed in total darkness. Photographs of landscapes or distant objects which are indistinct because of fine dust in the air may show clearly when plates sensitive to infra-red are substituted for ordinary photographic plate. Infra-red film is now on the market for use of the amateur in ordinary cameras.

Infra-red rays are being used in the treatment of certain diseases, particularly lumbago, neuritis, neuralgia, and rheumatism. Radiations

Fig. 378.—This photograph was taken without the aid of visible light. Only infra-red rays were used. It was taken on October 7, 1931, on the occasion of a visit of the National Research Council to the Eastman Research Laboratories.

from red-hot electric coils or carbon arc lamps are common. If the light from the arc is not desired it can be shut off by filters of glass colored with manganese and iron oxides. When you hold your hand between the eyes and close to a 100-watt bulb you see a strong red glow which indicates that the red rays have penetrated the flesh while the remaining shorter rays of light have not been able to go so deeply into the flesh. This suggests the possibility that the longer infra-red rays may penetrate even more deeply than the red rays do. It appears from experiments that infra-red rays just below the visible red have a good effect in penetrating the skin and warming the blood. Infra-red radiations from steam and hot-water radiators do not appear to have the same penetration or the same desirable effect. Little is actually known about the physiological action of infra-red rays, nor is it known which

rays are best for certain desirable effects. It is possible that a different type of radiation for heat in our homes would be better for health than that commonly in use. A field for research is open here.

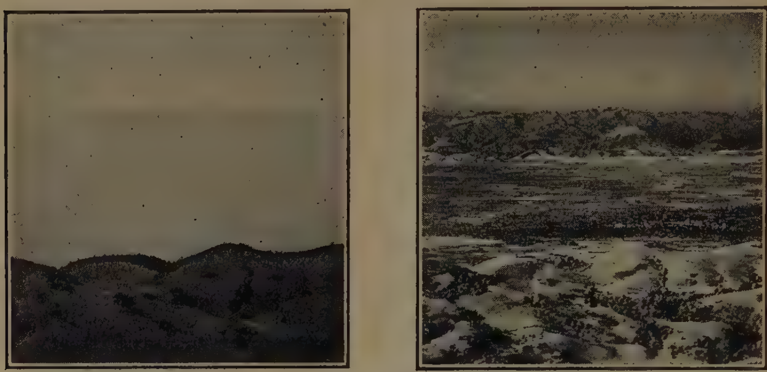


Fig. 379.—San Jose photographed from Mt. Hamilton, 13½ miles distant, at the same time but upon different kinds of plates. View at left was taken on an ordinary plate sensitive to violet rays. View at the right was taken on a plate sensitive to infra-red rays. Although it was a clear day, there was enough dust in the air to prevent passage of sufficient light to register on an ordinary photographic plate.

Use of neon gas. The long glass (or quartz) tubes bent to make letters for advertising purposes are tubes in which neon replaces the air. A discharge of high-tension electricity through this rarefied gas causes

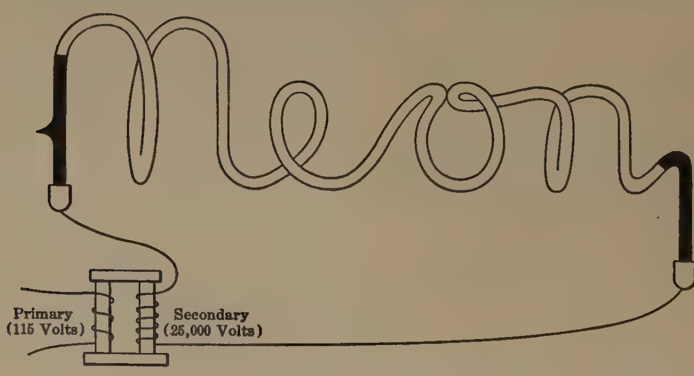


Fig. 380.—A common type of neon tube used in advertising.

it to become luminous and to emit a deep orange-red light which can be seen for long distances even in bad weather. This makes it a desirable lamp for traffic signals and airport beacons. If mercury is added to the neon before the tubes are sealed, a brilliant blue color is produced.

Ultraviolet rays. Ordinary incandescent lamps give out both heat (infra-red) and light rays, but no ultraviolet rays of importance. Sunlight gives an abundance of infra-red, visible light, and ultraviolet rays. The shortest ultraviolet rays from the sun are absorbed by the earth's atmosphere so that only the longer rays reach the earth's surface. Of all the energy sent out by the sun, 45 per cent is in the form of visible light. Tungsten lamps give only 4 per cent of the energy consumed as light; most of it appears as heat. It is not uncommon to have 7000 to 9500 foot-candles of visible light from the sun in summer. But it is believed that this is more than is needed for health. A part of the ultraviolet spectrum of sunlight is accepted as an important factor in maintaining health. Rickets has been cured by these rays, and it is known that they produce vitamin D. Ordinary glass excludes most of the ultraviolet rays, so that if we wish these rays from the sun to enter our houses we must have open windows or use a special glass capable of transmitting them. Because of the advantages believed to be derived from the ultraviolet rays many lamps have been devised to produce them. It is now possible to get from some of these lamps more ultraviolet and infra-red rays per foot-candle of light than we can from the sunlight. Furthermore, by means of special glass and filters the rays can be kept within limits of those believed to be beneficial to health. In one type of sun lamp (see Fig. 381) a tungsten filament heats mercury which is in the bulb, and the resulting mercury vapor produces an arc across

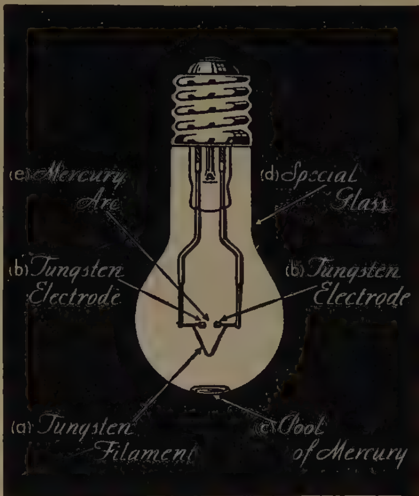


Fig. 381. — Sunlight lamp.

Fig. 382. — The mercury arc in the sunlight lamp.

a gap between two electrodes. Radiations are sent out both by incandescent tungsten and mercury and together give a wide range of wave lengths. A sunburn can be produced with this lamp quite as effectively as by real sunlight. The eyes should be protected by dark glasses unless one is careful not to allow the light to shine into the eyes. By Fig. 383 you will see that the special glass is transparent to ultraviolet rays having wave lengths of 2900 to 3100 Ångströms, which are excluded by ordinary glass. These are the rays that produce sunburn. Many rays which are shut out by the special glass will pass through quartz. The effect of many of these short ultra-

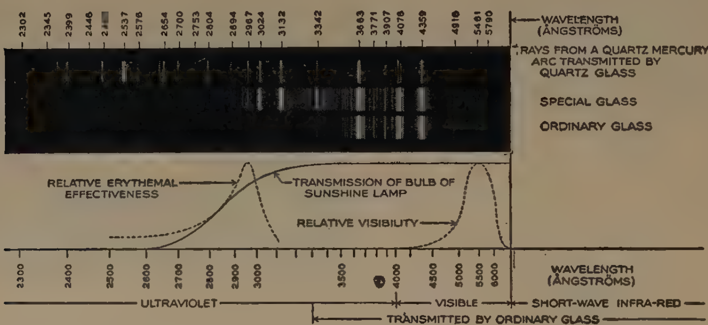


Fig. 383. — Transmission through different kinds of glass of ultraviolet rays produced by the mercury arc.

violet rays upon the health is not yet certain, but some are known to be harmful to the eyes. The chemical effect of ultraviolet rays upon silver salts is well known in photography, and its action in photosynthesis is responsible for the production of a large part of our food derived from plants.

A lamp giving ultraviolet rays in the region of 2537 Ångströms is used during surgical operations. The rays, directed upon the wound, kill all germs. The rays are not harmful to man. Special glass in the tubes allows the rays to pass. Such lamps are used to reduce mold, slime, and loss of water in meats as well as for sterilizing glasses at soda fountains and dishes in bakeries.

Electrical discharge in air. Air, usually an insulator, may under certain conditions conduct electricity. If free electrons can be separated from the neutral atoms, leaving the atoms positive, the air becomes *ionized;* in this condition it will carry an electric current. Ultraviolet light and radioactive substances are capable of ionizing air to some extent. Very high voltages are also able to ionize air, making it a conductor. From 10,000 to 75,000 volts are required, according to

the nature of the terminals, to carry the electric spark across a one-inch air gap. With pointed terminals, less pressure is needed. The high pressure from the secondary coil of an induction coil will produce a long spark, and the electrical discharge from clouds producing lightning is the result of enormous electrical pressure.

FIG. 384. — Electrical discharge in air.

An electrical discharge in a vacuum tube. When much of the air is pumped out of a tube which has metal terminals sealed in the ends and the terminals joined to the secondary of an induction coil, a silent electrical discharge takes place, and a glow of light fills the tube. The reduction in pressure helps to increase the discharge, as follows: The electrons have longer distances to move without colliding with molecules and, as a consequence, strike the molecules with greater force, thereby causing greater ionization. The greater the ionization, the greater is the electrical discharge that is possible. Under a pressure of one three-hundredth of an atmosphere, alternate light and dark bands appear to travel through the tubes. Such tubes are called Geissler tubes. The discharge in a Geissler tube may be fifty times as long as the spark produced in air at atmospheric pressure, under the same amount of electrical energy. Different colors result from different gases inside the tubes. Neon gives a crimson red. This is common in advertising signs and in tubes for testing whether spark plugs are firing correctly. A blue light results if argon is in the tube.

Cathode rays. In 1875, Sir William Crookes found that, when a tube was exhausted until the pressure was only one-millionth of an atmosphere, the glow present in Geissler tubes was absent. The molecules were so reduced in numbers that an electron rarely hit them. These invisible rays are cathode rays. They may be deflected by a magnet. They have the tremendous speed of 20,000 to 100,000 miles per second. When these rays strike the glass walls of the tube, they produce a yellowish green fluorescent light, but if an aluminum screen is in their path a shadow is cast. It is believed that these rays are a stream of electrons.

FIG. 385. — Geissler tube.

Dr. Coolidge, of the General Electric Company, has developed a

cathode-ray tube which takes a high voltage. Under a pressure of 350,000 volts the electrons pass through a nickel window in the end of the tube. Many substances placed in these rays in a darkened room glow with phosphorescent and fluorescent light.

X-rays. In 1895, Roentgen discovered that, when the cathode rays struck a solid body, new and unknown rays resulted which were invisible but which affected a photographic plate. These rays have since been called the X-rays. The cathode rays are streams of electrons, but the X-rays are ether waves. The modern X-ray tube — the Coolidge X-ray tube — has a vacuum pressure of only 1/15,000,000 of an atmosphere. This tube has a heated filament for the cathode. The hotter the filament the more numerous the electrons sent out and hence the greater the production of X-rays. The ordinary X-ray has a vibration rate of three millions of millions of millions per second, and the waves are so short it takes 250,000,000 of them to span one inch of space. The practical value of the X-rays lies in the fact that they are able to penetrate many opaque bodies.

FIG. 386. — X-ray tube.

X-ray tubes are of two types, hard and soft, for practical uses. *Hard rays* are more penetrating than *soft rays*. Bones are opaque to

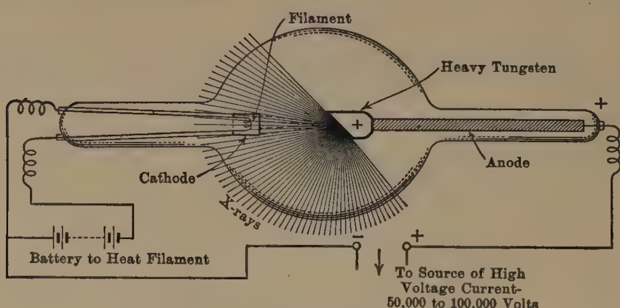


FIG. 387. — The Coolidge X-ray tube.

soft rays but transparent to hard rays. A metal shows up in bone by contrast under the hard rays. The hardness of a tube is determined by the gas pressure: the less the pressure the harder the rays.

By passing several million volts through high-vacuum tubes — super X-ray tubes — X-rays of vastly greater penetrating power have been produced experimentally. Whereas the ordinary X-ray will detect

flaws in a steel casting several inches thick, these super X-rays will penetrate several feet of metal. Under very high voltages the rays produced appear to be identical with the gamma rays which are given off by radium. Experiments give great promise of producing a substitute for radium. Some hospitals have recently been equipped with a one-million-volt X-ray machine.

FIG. 388. — The X-ray discloses a break in the bones.

Uses of the X-ray. The X-ray is most commonly used in the examination of a person for broken bones, or fractures, locating foreign bodies, and in studying the action of the organs of the human body. It is possible to watch the beating of the heart, to follow food through the digestive tract, and to detect the presence of ulcers at the roots of the teeth. When there are ulcers the tissue of the bone is eaten away. This allows more X-rays to penetrate and affect the photographic film as is shown in Fig. 389.

In industrial plants, the X-ray discloses flaws in castings and other

FIG. 389. — The light area around the roots of the teeth indicates ulcers.

FIG. 390. — Fluoroscope.

metal preparations. It helps jewelers to tell true from false gems. It is used by customs officials to detect smuggling.

For direct vision it is necessary to use a fluoroscope, which has a screen at one end of a box arranged to hold to the eyes and shut out ordinary light. When the X-rays strike the screen, which has a coating of fluorescent chemicals as platinum barium cyanide, the denser portions of the object stand out in contrast to the less dense. This is made possible because the X-rays cause the platinum barium cyanide to glow with phosphorescent light which is visible. Since the flesh is more transparent to the X-rays, more fluorescence is produced on the screen. The bones, being less transparent, cut off the rays and produce a shadow. A permanent record of the shadow may be produced photographically. The rays penetrate the usual hard-rubber covering of a plate holder, so that X-ray photographs may be taken in a lighted room.

Radioactivity. Radioactive substances are numerous. They include thorium, radium, uranium, and pitchblende, the ore from which radium is obtained. They constantly give off rays which affect photographic plates. By working about 500 tons of ore with an equivalent weight of chemicals, a gram of radium is obtained. This has the greatest radioactivity of any substance known. The white powder commonly used is radium bromide and not the metal radium itself. This radium salt is ever giving out radiations of three different types. When a radium salt is placed in a shallow lead box open at the top and a strong magnetic field is produced across the top of the box it will be found that the three kinds of rays are separated, as in Fig. 391. If we look across the box in the same direction as the lines of force — north to south — the alpha rays are deflected to the right, the beta rays to the left, and the gamma rays move straight up without bending.

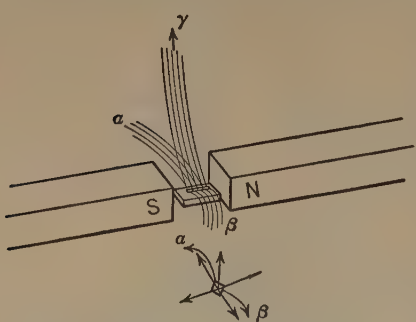


Fig. 391. — Separation of rays from radium in a magnetic field.

Properties of the radiation. The alpha rays are the nuclei of helium atoms having positive charges. They have very little penetrating power. The beta rays are just a stream of electrons, having the same properties as cathode rays. They move at about one-fifteenth of the speed of light. The gamma rays have many of the properties of X-rays and are now considered to be identical with X-rays of extremely short wave length which are produced by the new super X-ray

tubes. The photographic effect produced by radium is due to the gamma rays.

Scientists of the Carnegie Institution have built a coil capable of producing 5,000,000 volts. With an X-ray tube able to take 2,000,000 volts they can produce alpha and beta radiations in quantities equivalent to those produced by over one million dollars' worth of radium. Scientists are ever working for ways of making more practical use of this wonderful power. Notable results have been obtained by the General Electric engineers, by engineers at California Institute of Technology, at Stanford University, at the Massachusetts Institute of Technology, and at Princeton.

FIG. 392. — Scientists experimenting with high-voltage apparatus for producing the alpha and beta rays at the Department of Terrestrial Magnetism of Carnegie Institution, Washington, D. C.

Disintegration of radium. During the discharge of the rays from radium many intermediate products are formed. Elements of smaller atomic weights are produced. The solution of a radium salt in water yields a heavy gas (radon) which is collected in tiny tubes and used in place of radium in the treatment of cancer. The radon is strongly radioactive for a few days but gradually loses its radioactivity. These tubes of radon are well suited to medical use. They may be embedded in a cancerous growth without danger of too much action, since the radiations will cease to function before harm could be done. Radium itself is believed to be a product of the disintegration of uranium. Radium in turn disintegrates, producing other elements; the end product is lead.

Phosphorescent light. We are familiar with the luminous electric-light button, pull chain, door knob, and watch dial. This glow in the dark results from coating the materials with zinc sulfide to which a small amount of radium salt has been added. The alpha rays given off by the radium dislodge some of the electrons from the zinc sulfide, and as they move back into position the phosphorescent light is produced. Zinc sulfide is also able to show phosphorescence for a limited time in the dark after an exposure to light or ultraviolet rays. Strong light displaces electrons which return more slowly to their places. If the coating on your watch hand and dial contains radium, you can detect

it in a dark room by using a magnifying glass over it. If radium is present in the zinc sulfide coating, a series of bright scintillations will be seen resembling a fireworks display. An interesting instrument called a spinthariscope makes use of this property of the alpha particles. A small cylindrical tube contains a screen coated with zinc sulfide. A tiny speck of radium is mounted above this. A lens covers the top opening of the tube. When one looks through the lens in the dark he sees a series of sparks which result from the impact of the alpha particles upon the screen.

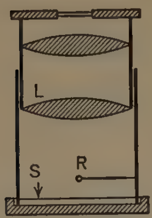


FIG. 393. — Spinthariscope. *L*, lens; *R*, radium; *S*, screen coated with zinc sulfide.

Cosmic rays. A charged electroscope loses its charge more rapidly on high elevations than at the bottom of the earth's atmosphere and retains its charge longest when dipped in sealed chambers deep below the surface of a body of water. Radiations capable of ionizing the air so that a charged electroscope will lose its charge are believed to come from distant space entirely outside the earth and solar system. These rays, called *cosmic rays*, have the shortest wave length known. There is some evidence to indicate that these cosmic rays are possibly produced when electrons and protons combine to build atoms of matter. Another hypothesis is that they may be a product of the splitting of super-giant elements into simpler ones in white giant stars.

SUMMARY

1. Short ether waves are measured in Ångströms. One Ångström is 1/100,000,000 of a centimeter.

2. Infra-red rays may be used to send messages, to take photographs in the dark, and to treat certain diseases.

3. Red light has considerable power in penetrating atmosphere charged with fine particles of dust or moisture.

4. Ultraviolet rays are of value in photosynthesis, in photography, and in maintaining health.

5. Ordinary window glass permits only a few of the ultraviolet rays from the sun to pass through. Special and quartz glass are more transparent to them.

6. The discharge of electricity in air depends upon the ionization, the electrical pressure, and the character of the electrodes.

7. Electric discharges through vacuum tubes are silent. The effects vary with the degree of the vacuum. Different colors result from having different gases in the tubes.

8. When cathode rays strike a solid they produce a fluorescent light. They also set up the invisible X-rays.

9. X-rays produce photographic action and pass through many substances which are opaque to light.

10. The fluoroscope has a prepared screen which becomes phosphorescent when excited by the X-rays. It shows shadows of bones and other bodies not easily penetrated by the X-rays.

11. There are many radioactive substances which give off alpha rays (the nuclei of helium atoms), beta rays (a stream of electrons), and gamma rays (short-wave X-rays).

12. Radium is the most radioactive of any substance. It disintegrates into simpler atoms. Its final product is lead.

13. Radium emanations are useful in the treatment of cancer and in the luminous coating for watch hands and dials.

14. Cosmic rays are the shortest forms of ether waves; they are believed to come from distant space.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Huygens, Newton, and theories of light waves.
2. Present-day uses of radium; of X-rays.
3. Look up *energy units,* quanta, or photons.
4. Medical uses of radiant energy.

CHAPTER XXVIII

RADIO

Sound waves and radio waves. Sound waves are vibrations in matter. Radio waves are vibrations in the ether. Our ears are constantly picking up sound waves which pass through the air surrounding us. Our eyes receive ether waves of certain lengths and make sight possible. Radio waves, ether waves much longer than those to which our eyes are sensitive, are constantly passing by us — even through us, for our bodies, our houses, and almost all materials are transparent to them; and yet we cannot detect them by any of our senses. There are devices which will change the ether waves, which we call radio waves, into sound waves or into light waves, and so make us aware of their presence and also give us the message which they bring as sound or vision. Among the most marvelous achievements of science are those which make it possible to change the sound of a person's voice and the light from a person's face into electrical or radio waves which traverse the ether at a speed of 186,000 miles per second and, at a distance of thousands of miles from the speaker, to have these waves received and changed back into speech and image so like the original that the voice and features can be recognized.

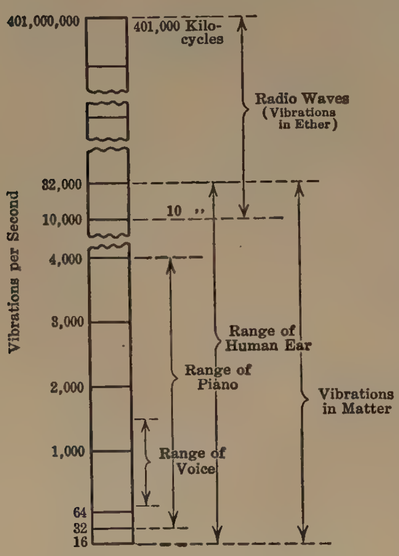


FIG. 394. — Range of sound waves in matter and radio waves in ether.

How wireless was developed. Whenever an electric spark is produced, as by discharging a condenser, the electricity surges back and forth, diminishing at each reversal. This fact was discovered in 1842 by Joseph Henry. The number of oscillations in a single second may be a few thousand or several million. The sparks of a static machine or induction coil which has condensers also are oscillatory,

and it is now known that they set up electromagnetic waves in the ether. Maxwell developed a theory that such waves existed, but not until 1888 were electromagnetic waves in the ether actually detected. Marconi learned of these experiments, which proved that electromagnetic waves would pass through the ether and could be detected, when he was only eighteen years of age. He at once resolved to make use of this wonderful way of carrying energy through space for the purpose of communicating between places widely separated. In 1894, Marconi had produced the first practical radio detector, called a **coherer**, and from then on he made rapid strides until 1896, when wireless was publicly demonstrated for the first time.

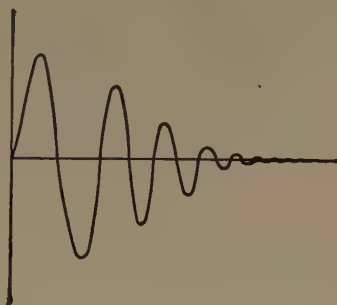


FIG. 395. — Oscillating discharge of an electric spark.

Resonance in sound. If a tuning fork having a frequency of 256 vibrations per second is made to vibrate, and is held near another fork whose vibration rate is 256 times per second, this second fork will vibrate and can be heard after the first fork is stopped. This is an example of resonance or sympathetic vibrations, explained in Chapter XXVI. The same thing happens when two steel wires of the same diameter are stretched between two supports. If they are under the same tension and we cause one wire, which is just 100 centimeters long, to vibrate, it will send out waves which are characteristic of these conditions and will set the second wire into vibration. If we try similar wires all having the same conditions except length, we shall find that only one length of the second wire will respond to vibrations in the first. If our second wire is 110 centimeters, 105 centimeters, or 90 centimeters, it will not be set into vibration when the first one vibrates, but if it is just 100 centimeters we find that it will produce sound. Changing the conditions of the second or receiving wire, to produce resonance, may be considered a *tuning* process. Thus, energy sent out by one body may be picked up, in part at least, by a second body, through a process of resonance.

Electrical resonance. We can demonstrate electrical resonance by means of two similar condensers, one of which has a varying circuit. One condenser, such as a Leyden jar, has joined to the outside coating a metal conductor whose other end is separated by a small gap from the knob G which joins the inside coating. This we shall call the *wave-producing* equipment: A in Fig. 396. The Leyden jar, A, may be given an electric charge by joining the two surfaces to the two terminals of

a static machine or to the secondary coil of an induction coil. Another condenser of the same capacity (B) is fitted with a metal conductor and has a spark gap at the knob (G'). This we shall call the *receiving* equipment: B in Fig. 396. The metal circuit is longer than that in the wave-producing equipment but has a cross sliding wire so arranged that the length of this circuit may be adjusted. When the condenser A is charged and a spark crosses the gap G, the oscillating discharge sends out waves in all directions. Tests are made with B by sliding S into various positions. Only when the circuit is in tune, that is, of the same resistance and inductance, will it pick up the wave. When it is in tune, at every wave sent out by a spark in A's circuit, a tiny spark will appear in the spark gap in the receiving circuit. The spark in the receiving equipment is due to electrical resonance, and you can readily understand how closely it corresponds to sound resonance, previously described. It is evident that, when an electric spark is produced, the electrical oscillations pass through the ether and will be absorbed by another circuit in tune with it, in sufficient amount to make the energy manifest.

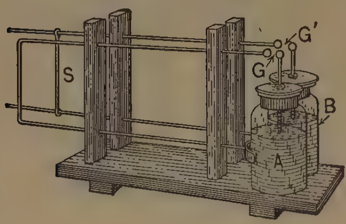


Fig. 396. — Electric resonance.

Radio broadcasting. The sending of speech and music by radio is more difficult than the sending of signals. Pulsating electric currents go from the microphone transmitter to the modulator and modify the carrier waves which are amplified and sent out from the antenna of the sending station. When sound is produced near this transmitter, it changes the resistance, just as it does in the ordinary telephone transmitter. As a result, every sound modifies the amplitude of the electrical waves. When there is no sound, the continuous waves (carrier waves) pass off through the ether and may be received by any appropriate receiver. When a person speaks, or other sounds are made, before the microphone transmitter, modulated waves pass off into the ether and will then be received by anyone whose set is tuned in. In the receiving set, the modulated waves are intensified by means of an amplifying unit and are rectified by a detector. Then the rectified pulsations set up

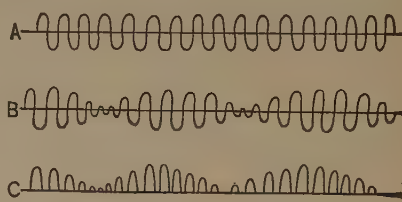


Fig. 397. — *A.* Continuous waves (carrier waves) produced in broadcasting sending apparatus. *B.* Modulated waves. *C.* Modulated waves rectified by the detector.

vibrations in the phone-receiver diaphragm, and this reproduces the sounds made in front of the microphone which modulate the carrier waves at the broadcasting station.

Crystal set reception. Ether waves will be received by receiving devices that are in tune with the transmitting apparatus by which the waves are sent out. By tuning to get the right length of wire at the coupler into the aerial-ground circuit, the electric oscillations will be picked up. (See Fig. 398.) This wave or current is alternating, and so induces a similar current in the secondary; but in order to cause the telephone receiver to produce sound, this alternating current must be rectified. This is done by the detector, which allows current to flow in only one direction. In the diagram a crystal detector is indicated. Each wave, representing a dot or a dash of the code, will make a sound in the receiver, and by this means the message is read. Variations in the waves from broadcasting stations are received as reproductions of the sounds made before the microphone in the broadcasting studio. The crystal set may be used for only short-distance reception.

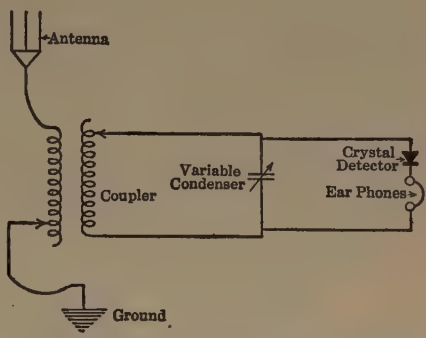


FIG. 398. — A simple crystal receiving hook-up.

Radio detectors. Detectors are devices which permit electricity to flow in one direction only. When the wave from the receiving aerial reaches the detector, all that part of the wave in one direction is stopped and all that in the opposite direction passes through. The wave which passes through, made up of impulses of direct current, is called the *rectified wave*. It is this rectified electric current that reproduces sound in the telephone receiver. We have already mentioned the crystal detector. Many kinds of crystals, when joined in a circuit with one wire loosely touching them, allow current to pass in one direction only. One of the best crystals is galena. The end of a very fine adjustable wire touches the galena loosely, thus closing the detector circuit between the antenna and ground in circuit with the tuning device and the earphones. The vacuum-tube detector is another device which is very much superior to the crystal detector, since it enables us to hear over greater distances.

The vacuum-tube detector. The vacuum-tube detector was used by the Marconi Company of England in 1902. In 1906 Lee de Forest, of

New York, made an improved tube which contained a *grid element.* Further development of the tube was slow, largely because of patent complications. During the World War the patent difficulties were straightened out and since then there has been rapid development of the tube which is now considered an essential to long-distance radio telephony. The vacuum bulb contains a filament like that in an incandescent lamp, a grid, and a metal plate. The metal plate is outside the filament, and between the filament and the plate is the grid. For battery sets these bulbs are made to take a 6-volt current to light the filament, or 1½ volts for the small tubes. The battery for lighting the filament is the *A* battery, and that for charging the plate is the *B* battery. The grid is charged by connection to the secondary circuit of the transformer and receives an oscillating charge. The plate is connected to the positive pole of a battery, usually giving 22½ to 45 volts.

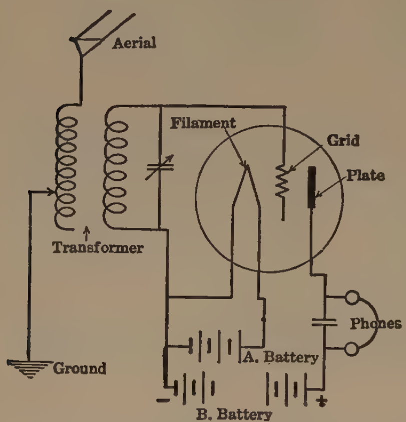


FIG. 399.—A simple hook-up with vacuum-tube detector.

Theory of action in a vacuum-tube detector. When a vacuum-tube detector is used, the antenna-ground circuit is made through the primary of a transformer. One end of the tube filament is joined to one end of the secondary of this coil. Thus, whatever oscillating or alternating current is picked up by the antenna is reproduced in the filament. The plate is joined to the positive pole of a battery, so that it has a constant positive charge. When the filament of the tube is glowing hot, it sends out electrons or negative electricity. The rarefied gas in the tube under these conditions becomes conductive, and during the positive phase of current received from the antenna a current of electricity passes across the gap between the filament and the plate. During the time that the negative phase of the alternating current is present in the grid, there is no passage of current across the gap to the plate. Electrons can pass in one direction through the tube, but not in the opposite direction. Thus the tube, which receives an alternating current, passes on only a direct current. This direct current operates the diaphragm of the telephone receiver. The purpose of the grid is to retard or accelerate the flow of electrons between the filament and plate. This is done by having the grid connected to one end of the

secondary, so that it alternately becomes positive and negative, the degree of change being regulated by the grid condenser.

Frequency and wave length. The velocity of radio waves in ether is approximately 300,000,000 meters per second. This velocity is the product of the wave length and the number of vibrations per second. Frequency means the number of vibrations per second. Thus, a wave of 100 meters must have a frequency of 3,000,000, and a wave of 3000 meters must have a frequency of 100,000. These figures are so large that a new frequency unit, the *kilocycle*, has been adopted. "Kilo" means a thousand, and "cycle" means one complete alternation. Kilocycle then indicates the number of thousands of times that the wave alternates in the antenna in 1 second. The frequency 3,000,000 is equivalent to 3000 kilocycles, and 100,000 to 100 kilocycles. Wave lengths used in radio vary from 30 meters to 30,000 meters in length, or from 10,000 to 10 kilocycles. The band of 150 to 200 meters for amateurs is a frequency band from 2000 to 1500 kilocycles.

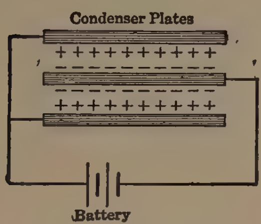


Fig. 400. — Charged condenser plates.

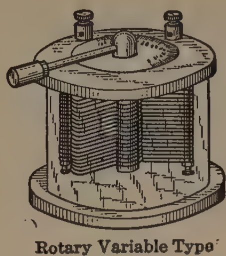


Fig. 401. — Variable condenser.

Inductance and capacity. When a current flows through a short, straight wire, there is practically no inductance. When a current flows through a coiled wire, a new current, opposite in direction, is induced at each starting and at each stopping of the current. This induced current opposes the primary current. The inductance increases with the number of turns of wire. If a non-induction coil is desired, the wire can be folded in the middle and the double wire wound upon a central core. Then the induction effect of one half of the wire just neutralizes that of the other half, and no inductance will result. The slide tuning coils and the loose-coupler are *inductance coils*.

A *condenser* is made up of metallic plates separated by a small gap filled with glass, mica, air, or some other insulating material. These

plates provide a place for holding opposite electric charges. The *capacity* of the condenser for holding electricity is increased by making the plates larger, by using more plates, and by making the gap between them smaller. In an alternating-current circuit, one plate has a positive and the other a negative charge for one instant, but the following instant the charges are reversed.

The principle of tuning. Two violinists, about to play together, will "tune up," that is, adjust the tension of the strings so that the corresponding strings have the same vibration rates and so give the same pitch. If a string having a vibration frequency of 256 is sounded, the string on the other violin which, by shortening, by tension, or in some other way, has acquired the ability to vibrate 256 times per second, will vibrate faintly, owing to the resonance previously explained. If such a string is placed near an orchestra or band which is playing, it will respond to the sounds due to 256 vibrations per second and to no others. In a somewhat similar way, tuning is possible in radio. An electromagnetic wave of 300 meters has a frequency of 1000 kilocycles. A receiving antenna circuit may be tuned to receive that particular wave frequency and wave length. In other words, the electrical length of an antenna can be changed by means of condensers and inductance so that one particular wave frequency is received by it better than any other wave frequency. There are various ways of changing the capacity of an antenna so that it will receive the waves desired. A coil of wire joined to the antenna increases its length; two coils, one turning within the other, as in the variometer, change the inductance; a variable condenser consisting of two metal plates near, but not touching, each other will also change the electrical length of the circuit.

Amplification. Two methods of amplification are common. Either may be used alone or with the other. These types are called *radio-frequency* and *audio-frequency* amplification. As a rule, when one only is used it is the audio-frequency. In radio-frequency amplification a specially designed transformer steps up the incoming radio wave before it goes to the detector. An amplifying bulb is also required. Audio-frequency amplification is achieved by means of a transformer with closed core made of laminated iron. The secondary coil has nine times as many turns as the primary; this increases the voltage on the grid. Four stages of either radio-frequency or audio-frequency are likely to produce disagreeable howling, but a combination of two radio-frequency and two audio-frequency stages will give the equivalent four stages of amplification without the disagreeable noise.

The vacuum-tube amplifier. The amplifying tubes are similar to the detector tubes but have a higher vacuum. The filament is usually

coated with rare metal oxides which emit electrons when heated. The plate is joined to the positive terminal of the battery whose negative terminal is joined to the filament. The grid, which is located between the plate and filament, is the control electrode, as explained for the detector tube. One terminal of the alternate current which is to be amplified is joined to the grid, the other to the filament. When the alternate current makes the grid more positive than the filament, the electron flow to the plate is increased; but when the grid is more negative than the filament, the flow is decreased.

The increased current from the one tube may act on the grid of a second tube to increase the plate current in that. It may be amplified again and again until the desired strength is obtained. In theory, the three-element tube passes current only in one direction, but in fact there is enough leakage in the opposite direction so that, if amplified several times, serious squeals result. The screen-grid tube — a four-element tube — remedies this defect. In this tube a wire screen between the plate and the grid prevents electrons from leaking back and therefore allows greater amplification without the annoying sounds. A five-element tube — the pentode — permits still greater amplification than the screen-grid tube and so allows satisfactory volume with a smaller number of amplifying tubes. The pentode tube has a cathode grid between the plate and the screen grid. The pentode is used in the audio-frequency portion of the receiver. A variable-mu tube — a type of four-element screen-grid tube — has the grid made in sections of variable mesh, with the wires spaced closer at one end than at the other; it is used in the radio-frequency portion of the receiver. Its advantages are greater amplification and the reduction of hum.

FIG. 402. — Radio tubes. Mounts cut away to show construction. Screen-grid tube is the one at the left. The one at the right is a power amplifier. A three-element tube with coated filament; battery model.

Receivers. The earphones for radio telephone reception have higher resistance than those for regular telephone service. Those used only for code reception may have diaphragms made more sensitive to vibrations near "high C," which is the usual pitch of the spark telegraph code. This is not a satisfactory phone, however, for radio

telephone reception. A diaphragm which responds equally to all pitches will give less distortion. A delicate mica diaphragm, having a small armature at its center, is better than the all-iron diaphragm.

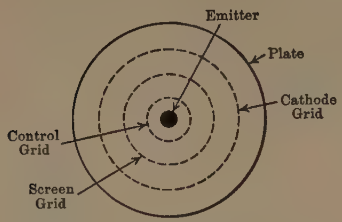


FIG. 403. — Arrangement of elements in the pentode tube.

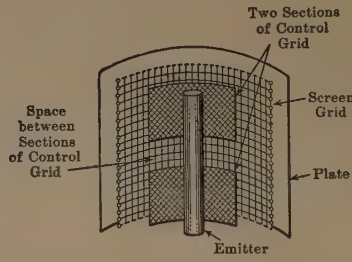


FIG. 404. — Construction of variable-mu tube.

The dynamic loud speaker. This type of speaker gives very satisfactory reproduction of sound. It consists of a strong electromagnet and moving coil having a fluctuating current. The moving coil surrounds one end of the core of the electromagnet. The electric vibrations from the audio-frequency amplifiers produce the fluctuating current in the moving coil. The moving coil is joined to a cone of some material similar to stiff parchment paper which is caused to vibrate in synchronism with the vibrations of the moving coil. The cone sets up sound waves in air which duplicate those made in front of the microphone at the broadcasting studio.

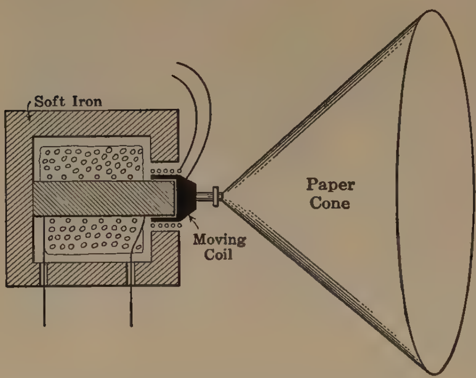
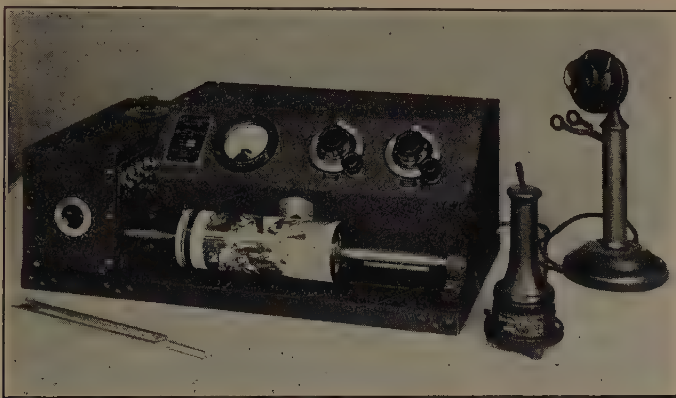


FIG. 405. — Dynamic loud speaker.

The radiophone. Long-distance international radiophone communication has increased rapidly since 1927 when service was opened between New York and London. Today nearly all the great countries of the earth are equipped for commercial radiophone communication. In radio chain broadcasting a person in one studio speaks into the microphone and the voice is carried as equivalent electrical impulses by telephone wires to many different stations, each of which sends it out as ether waves. The same principles are utilized in the radiophone. In

talking by radiophone to a person in England or France, a person in America talks into his own telephone transmitter and his words go as electric impulses to the transmitting station which is the terminal for all the land wire telephone circuits. There the electrical impulses are automatically changed to short radio waves which are picked up on the other side of the ocean by the receiving stations. The impulses are amplified and transmitted by wire phone to the other party. So rapidly do the impulses travel that conversation is carried on as easily as when the two speakers are face to face.



Wide World Photos.

Fig. 406.—Wired photo transmitter.

Picture transmission. Photographs are transmitted daily across the country on telephone wires and across the ocean by radio. This **wire photography** is a process of communication by which light waves reflected from pictures, drawings, printed matter, or objects are converted into electric signals and sent by radio or telephone circuits to distant points. The process is called **facsimile,** and a permanent copy of the original is made at a distant station. By means of facsimile service, weather maps are now sent to mariners at sea, and photographs are sent across the ocean. Facsimile is the process by which you may some day have your own newspaper printed in your home. The news may be brought in by your radio and with the additional equipment the printing be done. This can all go on automatically while you are asleep, and your news sheet will be ready when you arise in the morning. Several broadcasting stations are licensed to do this and are carrying on experimental work. Two devices of fundamental importance in the transmission of pictures by wire or radio are the photoelectric cell and the neon lamp.

The photoelectric cell. One type of photoelectric cell is a globe from which the air has been pumped and a small amount of an inert gas added. There is a transparent space in front through which light from the object may pass. The side opposite the window is coated with one or more of the alkali metals, generally cesium. Two wire electrodes enter the cell; one is joined to the cesium coating, and the other terminates in a nickel ring in the center of the cell. Many of the commercial cells use selenium in place of the cesium. A battery is joined to these

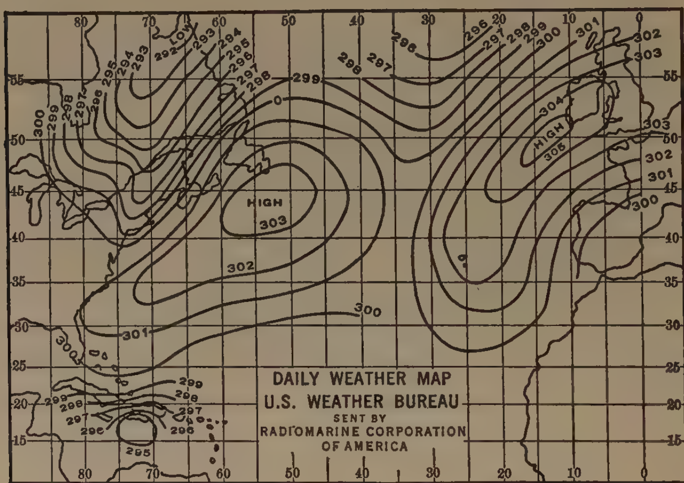


FIG. 407.—Radio weather map.

wires, but no current flows when it is dark within the cell. When light falls upon the alkali metal coating, electrons are thrown off in proportion to the intensity of light. These electrons pass across the space from the negative coating to the positive metal ring and thus produce a current of electricity in the circuit. The amount of current is small but varies with the intensity of light. This small current may be stepped up by amplifiers so that it is capable of modulating the transmitter.

The applications of the photoelectric cell are increasing rapidly. It is used in systems of television and in transmission of pictures by wire. It will turn water on at drinking fountains and open a door when a person approaches and cuts off a beam of light passing into the cell. It counts people, sorts objects by color, measures intensity of light for photographers, and tells the amount of illumination in the home or factory. It is used in sound-picture projection. It can auto-

matically turn the lights on in a room when it is too dark and turn them off again when daylight is sufficient.

The neon lamp. The neon lamp is a glass bulb from which air has been pumped out and then partly filled with neon gas. There are two metal plates inside the bulb with wire connections from outside. Every high-pressure electrical impulse causes a glow of light which continues as long as the current is sustained. The intensity of the light varies with the voltage. The lamp is used to print the pictures sent over the telephone wires by wired photo or by radio in facsimile. The variations in brightness of the lamp duplicate the variations in brightness given to the transmitting apparatus by the photograph at the sending end of the line.

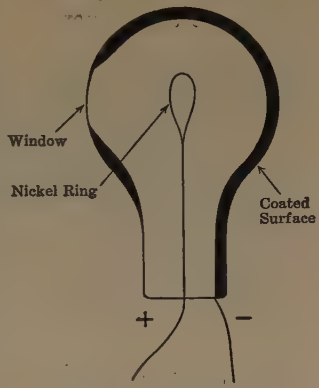


FIG. 408. — Photoelectric cell.

Television. Technically, television is ready for use. This has been demonstrated by experiments conducted for several years. A small but fairly satisfactory picture for a small group in the home can be sent and received by radio. The sending distance is far shorter than in regular radio broadcasting. For country-wide broadcasting the chain would require many more stations than are included in the present systems of chain hook-ups. The picture cannot be sent from the originating studio to the members of the chain by telephone wires like the broadcasting of sound. Instead, very expensive coaxial cable is required. A coaxial line from Philadelphia to New York has been used for experimental work. Television receivers are, at present, much more expensive than sound receivers. This means a smaller audience, less advertising value, and less money to pay for producing worth-while programs. In time new improvements and cheaper sets will undoubtedly bring television into our homes. Many systems have been devised for sending motion pictures by radio. Perhaps the best is one using two instruments called the **iconoscope** and the **kinescope.**

The iconoscope. The iconoscope — the eye of television — is the transmitting instrument whose important parts are vacuum tube, mosaic screen, electron gun, deflecting coils, and photographic lens. The heart of the iconoscope is a mosaic screen made up of millions of photoelectric cells. Each cell consists of a tiny droplet of silver coated with cesium and deposited on a sheet of mica. Behind each photoelectric cell on the other side of the mica is a nickel plate; together they form a

condenser. The plate of nickel which is back of the mosaic screen is called the *signal plate*.

Suppose that a person is in front of the iconoscope in a very bright

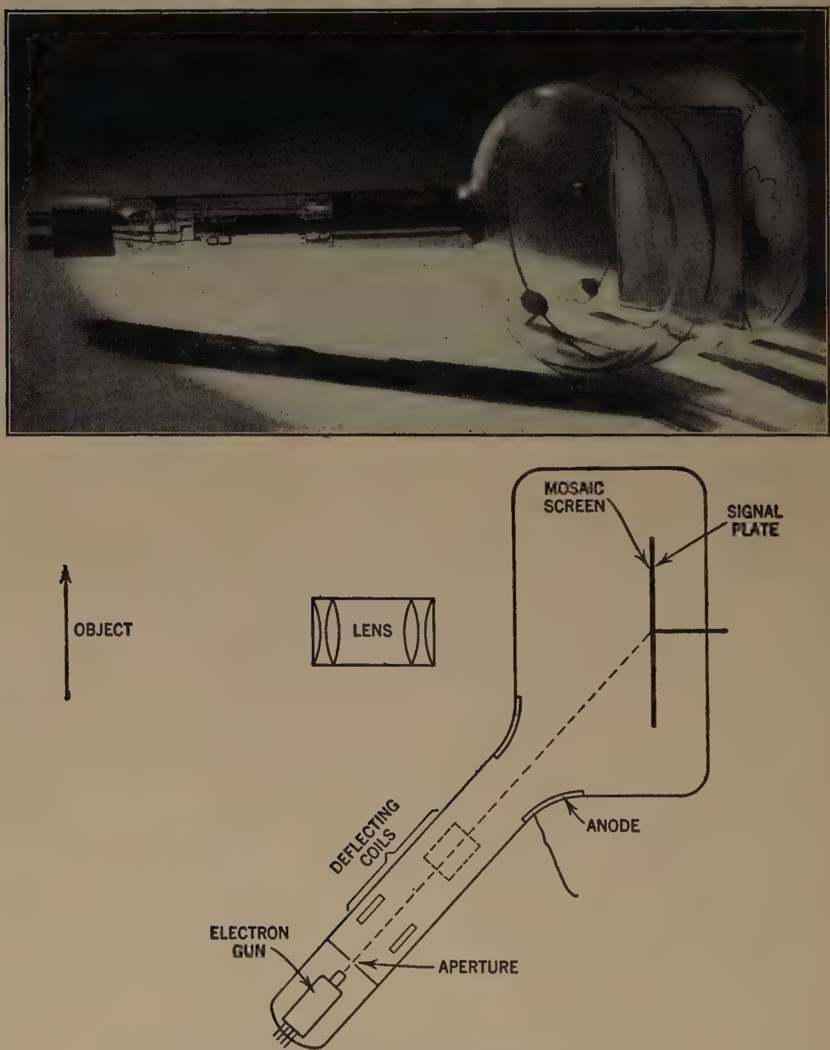
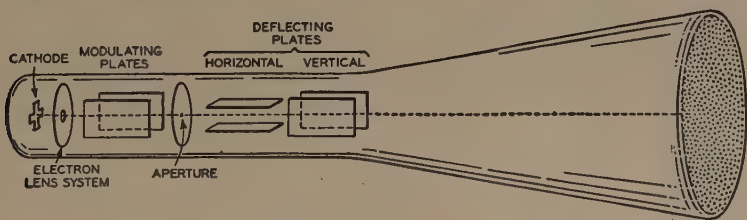


Fig. 409.—The iconoscope with schematic diagram.

light. A photographic lens projects the image of the person upon the mosaic screen. The light received by the photoelectric cells causes the emission of electrons in proportion to the brightness of the image. The electric charge is stored up in each small condenser. A stream of

electrons from the electron gun is under the control of the electromagnetic deflecting coils. These coils cause the beam to scan the mosaic, causing it to reach every part of the mosaic in turn in a definite sequence. When the beam touches a given photoelectric cell it supplies electrons and releases the charge on the nickel plate, starting an electric current which is the television signal. A succession of these signals, as the picture is rapidly scanned, is transmitted by radio from the broadcasting station.



Schematic representation of the cathode-ray equipment at the receiving end

FIG. 410. — The kinescope with schematic diagram.

The kinescope. The kinescope is the television receiver. It is a cathode-ray tube with high vacuum. It has, within the vacuum tube, an electron gun, deflecting coils, and at one end a fluorescent screen. That part of the fluorescent screen which is hit by an electron becomes luminous for an instant. The kinescope is usually funnel shaped. In the narrow neck is the cathode which sends out millions of electrons. The screen emits light at any point where electrons strike it. The electron beam is made to scan the screen by means of the deflecting electromagnets. It does this at the same rate as the scanning beam in the

iconoscope. The incoming radio signals are brought to the kinescope and cause variations in the discharge of electrons and consequently in the brightness of each spot on the screen. The whole picture painted by

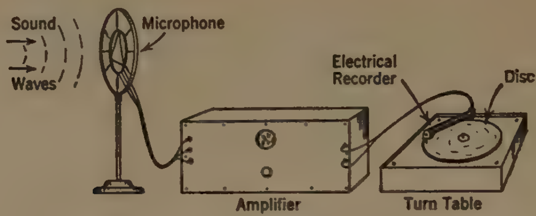


FIG. 411.—Making a phonograph record by electrical method.

the electron beam is a series of light dots—of varying intensities—swept across the screen in lines so fast that to the eye they appear to be there all at one instant. The speed of transmission is 441 lines per second.

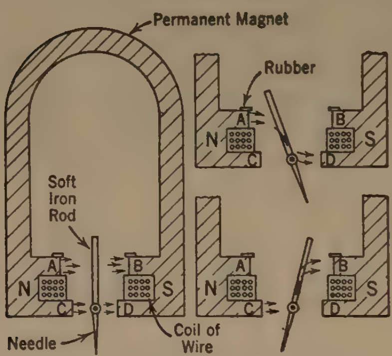


FIG. 412.—Phonograph pickup.

Making a phonograph record. Some of the devices used in radio make possible the production of disc records by a method of electrical sound recording. A microphone changes sounds into a pulsating electric current. This is amplified and then changed back into mechanical vibrations in the electrical recorder which causes a special cutting needle to make a master record on a disc. From the master record any number of copies can be taken.

The phonograph pickup. If you have a phonograph-radio combination, you are not limited to the old-time mechanical reproduction of sound. The new method uses a phonograph pickup which converts vibrations of the needle into varying electric currents. You will notice in the diagram that when the soft iron rod is in a vertical position the lines of magnetic force go from north to south along two paths: A to B and C to D. The point of the needle is in the groove on the record. As it is moved from side to side by the groove its position changes. During one complete vibration it moves so that it carries the magnetic lines of force from A to D and then from C to B. This movement of the lines of force around the coil of wire, shown in section inserted within the magnetic poles, induces an alternate current in the coil. This cur-

rent goes to the primary coil of a transformer in the amplifier. The pulsations of current are determined by the vibrations of the needle. After they have been amplified and rectified they operate a loud speaker which reproduces the sounds that were made in front of the microphone.

SUMMARY

1. Radio waves are ether vibrations. Sound waves can be changed into equivalent ether waves, which can be changed back into sound.

2. There is a close analogy between the behavior of sound waves and that of the ether waves of radio. Both are oscillatory, both produce resonance in bodies capable of similar vibration, and both may be detected by means of such bodies.

3. A spark produced in a high-tension circuit sends out waves which are detected by suitable equipment properly tuned.

4. In the radio telephone, sound waves change the resistance in a microphone transmitter. Continuous high-frequency waves, which are passing all the time, are in this way modified. The resulting modulated waves travel through the ether. In the receiving apparatus, the modulated waves are rectified so that they will act on a telephone receiver, by which the sound is reproduced.

5. Crystal detectors and vacuum-bulb detectors permit current to flow in only one direction. Because of this property they are able to rectify the incoming electrical waves, so that they will set up vibration in a telephone receiver.

6. The vacuum-bulb detector has a filament surrounded by a grid, and a metal plate outside the grid. When the filament is lighted and the plate given a positive charge, positive charges from the antenna cause electrons to flow from the filament to the plate. No electrons can flow in the opposite direction. This gives a rectified current to the phone receiver. The grid is a device for regulating the electron flow.

7. Wave length is usually given in meters and frequency in kilocycles. A kilocycle is the number of thousands of times a wave alternates in a second. The velocity of radio waves is 300,000,000 meters per second.

8. At the starting and stopping of a current in a coiled wire, opposing currents are induced. The amount of this inductance depends upon the number of turns in the coil.

9. A condenser consists of two or more conductors separated by insulators. The larger the plates, or the more of them, the greater the capacity.

10. In sound, one string is in tune with another which has the same vibration frequency. In a similar way, one electric circuit is in tune with another when it is capable of receiving radio waves of the same frequency which another circuit sends out. Tuning a receiving set consists in adjusting the different devices so as to produce electrical resonance.

11. Amplification is accomplished by stepping up the radio wave either before or after it goes to the detector. When done before detection, it is called radio-frequency amplification. If done after the wave has passed the detector, it is audio-frequency amplification. Amplification bulbs have a higher vacuum than detector bulbs.

12. Screen-grid and pentode tubes have extra elements which increase their capacity and make possible the same amplification with a smaller number of tubes.

13. Radio phone receivers have higher resistance than ordinary telephone receivers.

14. Loud speakers are devices for producing greater loudness by giving the diaphragm greater amplitude of vibration. In the dynamic loud speaker a moving coil is given vibrations by the varying electric current. This coil sets a parchment paper into vibration and this produces sound waves in air.

15. The photoelectric cell is a valve through which an electric current may pass when light stimulates action by shining into it. Light sets electrons free from the potassium, cesium, or selenium coating, and these complete the circuit between the coated surface and the positive metal ring.

16. Photographs and drawings can be sent by wire and by radio. The photoelectric cell and the neon lamp are useful devices in this process.

17. In television, a beam of electrons scans the image of an object on the mosaic screen of the iconoscope and sets up electric currents which after amplification are sent out by radio or wire. After being received and amplified, the electric impulses are changed into light in the kinescope.

18. Phonograph discs are now made by a process of electrical recording.

19. Induced electric currents in the phonograph pickup are amplified and operate a loud speaker with reproduction superior to that of the older mechanical system.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. International radio service.
2. Government control of radio transmission.
3. A homemade radio receiving set.
4. Radio broadcasting.
5. Motion picture. *Wizardry of Wireless.* (Film No. 40.) Two reels. General Electric Company.

INDEX

Note: Numbers in heavy faced type refer to pages containing illustrations as well as descriptive text.